CORPS OF ENGINEERS, U. S. ARMY

SPILLWAY AND OUTLET WORKS
EAST BRANCH RESERVOIR, CLARION RIVER
PENNSYLVANIA

MODEL INVESTIGATION

TECHNICAL MEMORANDUM NO. 2-325

WATERWAYS EXPERIMENT STATION

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PREFACE

Model studies of the outlet works and stilling basin for the East Branch Reservoir, Clarion River, Pennsylvania, were authorized by the Chief of Engineers, U. S. Army, in second indorsement dated 21 May 1947 to a letter of the District Engineer, Pittsburgh District, CE, dated 31 January 1947. The studies were conducted at the Waterways Experiment Station during the period September 1947 to March 1949.

During the course of the studies Messrs. T. B. Brett and W. W. Hibbs of the Pittsburgh District, CE; Mr. R. L. Irwin of the Ohio River Division, CE; and Mr. J. H. Douma of the Office, Chief of Engineers, visited the Waterways Experiment Station to discuss test results and to correlate these results with design work concurrently being carried on in the District Office. Engineers of the Waterways Experiment Station actively connected with the model studies were Messrs. F. R. Brown, T. E. Murphy, R. E. Barry, T. J. Buntin and G. B. Sims.

CONTENTS

SUMMARY

Model investigations of the spillway and outlet works for the East Branch Reservoir, Clarion River, Pennsylvania, were conducted to insure satisfactory over-all hydraulic functioning of these structures. Particular attention was given to development of a dispersal bucket at the lower end of the side-channel spillway and to the performance of the slide gates, tunnel, and stilling basin of the outlet works. Three models were used in the studies: a 1:50-scale model of the side-channel spillway, a 1:25-scale model of the outlet works, and a 1:12-scale model of one slide gate.

The spillway dispersal bucket was required not only to dissipate effectively the energy of flow, but also, because of certain terrain features of the exit area immediately downstream, to insure that the left bank would not be subjected to excessive scouring action and that flow would not impinge directly upon the right bank. Several designs tested for the spillway dispersal bucket indicated satisfactory dissipation of energy of flow. It was found, however, that a bucket with the following elements gave the most desirable distribution of flow: a curved left wall raised 10 ft above the height of the end sill, and an end sill with upstream face on a 1-on-1 slope and with the straight leading edge forming an angle of 1 on 5 with the center line of the chute. It also was determined that the spillway coefficient could be increased, without producing dangerous negative pressures, by shaping the weir to conform to the nappe of a 12-ft head, although the design flood produced a 17-ft head on the weir. This increase in the discharge coefficient permitted a 10-ft

reduction in the length of the spillway crest.

Tests of the intake structure and tunnel indicated satisfactory operating conditions for all flows, except with one gate completely closed and the other open approximately 10 ft. For this latter condition, large air pockets formed in the upper end of the tunnel, traveled rapidly along the tunnel, and passed into the stilling basin. This caused sudden pressure increases in the tunnel and considerable turbulence in the stilling basin. This condition was eliminated by the addition of a 1-ft-wide by 2-ft-high vane along the center line of the transition from the end of the separation pier to the beginning of the tunnel. Performance of the original stilling basin for the outlet works was satisfactory for all discharge conditions. However, it was found that economy in construction costs could be effected, without materially altering the flow conditions, by terminating the left training wall at the end sill.

An investigation of pressures on the original control gate for various openings indicated negative pressures near the bottom of the gate. The addition of a small lip along the lower edge of the original gate eliminated these negative pressures.

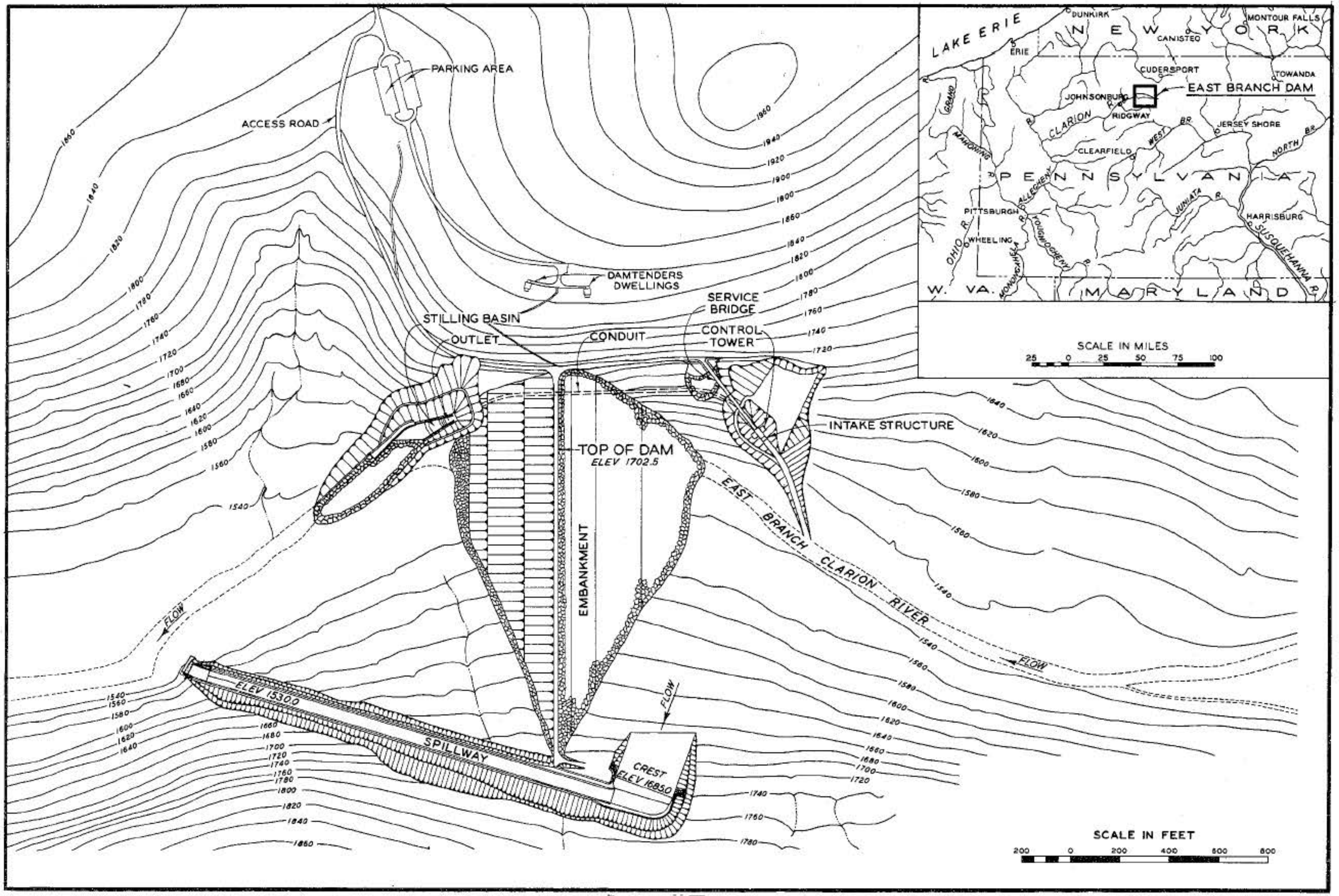

Fig. 1. Vicinity map and general plan of East Branch Dam

SPILLWAY AND OUTLET WORKS

EAST BRANCH RESERVOIR, CLARION RIVER, PENNSYLVANIA

Model Investigation

PART I: INTRODUCTION

The Prototype

1. The East Branch Reservoir is proposed for construction on the East Branch of the Clarion River, a tributary of the Allegheny River. The proposed dam site is located approximately 6 miles north and upstream of Johnsonburg, Pennsylvania, and about 115 miles northeast of Pittsburgh, Pennsylvania (fig. 1). The project will provide for the control of floods on the East Branch of the Clarion River, thus furnishing protection for Johnsonburg and Ridgway, Pennsylvania. The reservoir is one unit in the comprehensive flood-control plan for the Ohio River Basin. The dam (fig.1) will be a rolled-earth-fill embankment with a rock-faced upstream slope. It will have an over-all length of 1,660 ft and maximum height of 184 ft. The structure will be flanked on the right by the outlet works, and on the left by a concrete spillway of the side-channel type ending in a dispersal bucket approximately 1,400 ft downstream from the dam. The reservoir will have a capacity of 84,300 acre-feet at maximum pool elevation.

2. The side-channel spillway will consist of an approach, an ogee-type weir, a longitudinal channel, and a dispersal bucket. The spillway was originally designed to pass a maximum outflow of 69,500 cfs under a head of 17.0 ft with a length of 260 ft. However, as a result of the model tests it was found that the spillway discharge coefficient could be

increased sufficiently by reshaping the crest to allow the length to be reduced to 250 ft. The change of length was not effected in the model. A straight-walled concrete approach leading to the weir was planned originally; however, the walls were revised during the tests so as to provide curves of 25-ft radius on each side of the approach (plate 1). From the approach, flow will pass over the ogee-type weir into the upper end of the spillway channel at right angles to the center line of the inlet channel. The concrete-lined spillway channel will have a 7.5-ft vertical step at its upper end, and will terminate in a dispersal bucket at the lower end. This dispersal bucket was designed to obtain dissipation of energy of flow at a minimum construction cost, and originally consisted of a spoon-shaped flip bucket patterned after that used at Fontana Dam, Little Tennessee River. The bucket recommended as a result of the model tests (type D1 herein) was flat-bottomed and ended in a 15-ft end sill on a 1-on-1 slope (plate 18).

3. The outlet works will consist of a control tower having two rectangular gated passages leading into a transition section which will convey flow to a 10-ft-diameter circular conduit. Flow will be controlled by vertical slide gates. The conduit will be approximately 1,250 ft in length, and will have a horizontal curve in the upper and lower ends. A transition section will be provided on the lower end to convey flow to the stilling basin. The stilling basin will have an over-all length of 156 ft with stepped inlet and a parabolic-shaped stepped end sill. The outlet works will have a maximum capacity of 5,000 cfs. Negative pressures encountered in tests on the original design of the slide gate were eliminated by the addition of a small lip along the lower edge. Tests of the outlet

works indicated that satisfactory performance could be obtained by the addition of a low separator vane along the center line of the transition section from the separation pier to the beginning of the circular tunnel.

4. The following data pertain to the structural and hydraulic features of the revised design.

Structural

Approach:	Width		250 ft
	Flare		25-ft radius
	Slope		1 per cent
Spillway:	Width of crest		250 ft
	Elevation of crest		1685
	Height, crest to channel		49.5 ft
	Total length of longitudinal channel		2210 ft
Elevation of channel:		Upper end	1643.0
		Terminal bucket	1530.0
Slope of channel:			2.86 to 12.00 per cent
Outlet works:	Service gates		Two 3 ft, 4 in. wide by 12 ft high, vertical sliding
	Conduit:		Circular (10 ft inside diameter)
	Length		1249 ft
	Elevation, inlet end		1531.0
	outlet end		1524.38
	Stilling basin:		
	Type		Stepped inlet and parabolic-shaped stepped end sill
	Bottom elevation		1510.0
	Length		156.0 ft

Hydraulic

Maximum discharge through conduit	5,000 cfs
Maximum discharge over spillway	69,500 cfs
Maximum flood of record	25,000 cfs
Maximum head on crest	17.0 ft
Maximum pool elevation	1702
Maximum tailwater elevation	1547.0
Design head	12.0 ft

Need for Model Analysis

5. A number of specific problems were encountered in designing both the spillway and outlet works of East Branch Reservoir even though the design of the hydraulic structures was in accordance with good hydraulic practice. Confirmation or refinement of the original solutions for these problems by means of hydraulic model tests was desired prior to construction. Specifically, the adequacy of the design of the overflow portion of the spillway and the runoff channel was to be investigated. The effect of the step at the head of the channel and the possibility of its elimination, as well as the effect of submergence on the rating curve of the spillway, were of particular interest. The geological conditions in the exit area limited the types of dispersal bucket that could be used, and a model study of the various designs was necessary in order to insure proper performance. As regards the outlet works, it was desired to test the adequacy of the over-all design with particular emphasis on any flow eccentricities caused by the curvature of the conduit. The most economical stilling-basin design for dissipation of conduit discharge was to be developed. It also was desired to check the slide-gate design for undesirable characteristics.

The Models

6. Three models, two of which are shown in fig. 2, were used to accomplish the desired studies. A 1:50-scale model reproduced the side-channel spillway and the dispersal area; a 1:25-scale model of the outlet works included the control structure, conduit, stilling basin and exit area; and a 1:12-scale model of a slide gate was employed for a

comprehensive investigation of the gate-lip details.

Side-channel model

7. The model of the side-channel spillway was contained in two brick and concrete flumes with a concrete spillway chute connecting the two flumes (plate 1). The inlet area, weir, longitudinal channel, dispersal bucket, and approximately 1,200 ft of the river below the dam were reproduced. The entire model was molded in cement mortar to sheet-metal templets. Those elements representing concrete structures in the prototype were given a very smooth finish, while the remaining areas were given a brushed finish. Extreme care was taken in shaping all parts of the model to be sure that exact conformity with the prototype was secured.

Outlet works model

8. The model of the outlet works reproduced the intake tower,

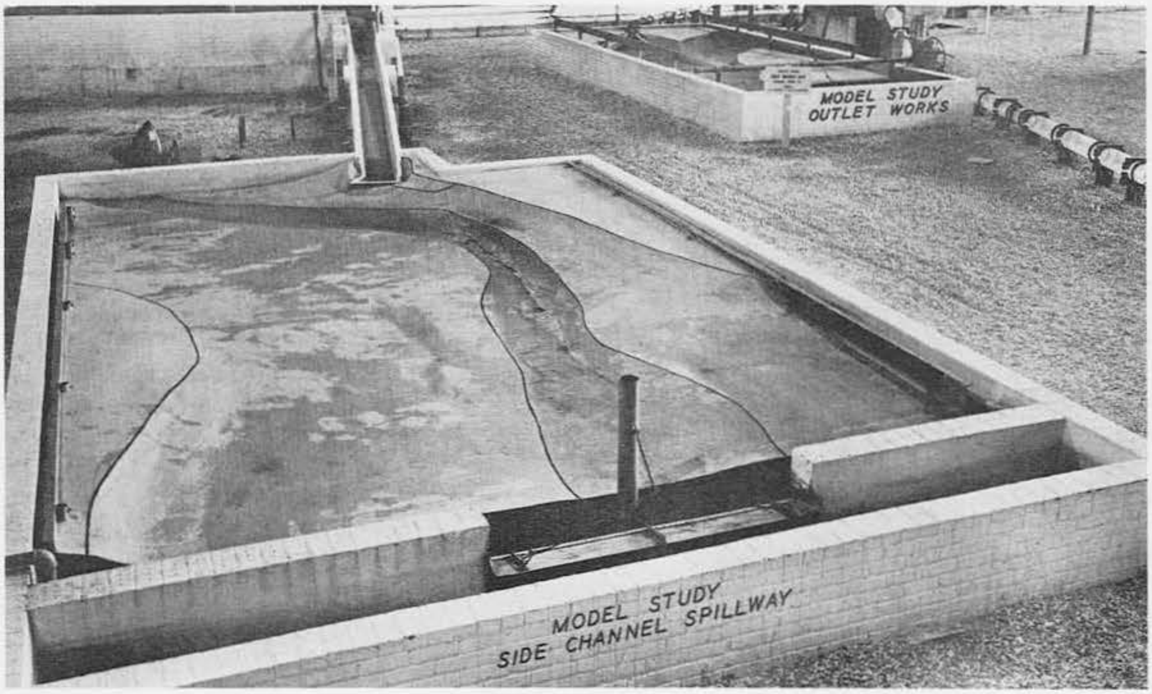

Fig. 2. View of side-channel spillway and outlet works model

conduit, stilling basin, and approximately 600 ft of the exit area (plate 2). The intake tower and the conduit were constructed of plastic, while that portion of the model representing the stilling basin was molded in cement mortar to sheet-metal templets. The exit area was molded in sand for scour tests; for velocity tests this sand bed was rendered immovable by application of a thin coat of cement mortar. Care was taken to shape properly all surfaces and to make them as smooth as possible.

Slide gate model

9. Tests on one of the slide gates were conducted in an existing conduit. The height and cross section of the gate were reproduced to a scale of 1:12; however, the width of the existing conduit made it necessary to use a model gate of greater width than that proposed for the East Branch outlet. Tests were concerned with pressures on the gate lip and were conducted on the original and one alternate gate lip.

Design Considerations

10. In the design of the models, geometric similitude was attained between model and prototype by selecting an undistorted scale ratio. The accepted equations of hydraulic similitude, based upon the Froudian relationships, were used to express the mathematical relationships between the dimensional and hydraulic quantities of the model and the prototype. General relationships existing for the East Branch models are presented in the following tabulation:

Dimension	Ratio	Relationship: Spillway Model	Outlet Model	Slide Gate Model
Length	L_r	1:50	1:25	1:12
Area	$A_r = L_r^2$	1:2500	1:625	1:144
Velocity	$V_r = L_r^{1/2}$	1:7.071	1:5	1:3.464
Discharge	$Q = L_r^{5/2}$	1:17,683	1:3125	1:499

Interpretation of Model Results

11. Certain of the model data may be accepted quantitatively, while other data are reliable only in a qualitative sense since complete dynamic similitude and accurate reproduction of some properties of the prototype materials cannot be attained. Measurements in the models of discharges, water-surface elevations, velocities, and pressures (all positive and negative pressures corresponding to pressures above the cavitation range in the prototype) can be transferred quantitatively to the prototype by means of the above scale relationships. Evidences of scour, however, are to be considered only qualitative, since means have not yet been developed to reproduce in a model the resistance to erosion of prototype bed material. The data on scour tendencies provide a basis for resolving the question as to the relative effectiveness of various types and locations of basin elements, and serve to indicate the areas most subject to attack. Determination of the actual depth of scour to be expected in the prototype should be predicated upon the magnitude of bottom velocities and characteristics of the prototype bed material.

PART II: NARRATIVE OF TESTS -- SPILLWAY

12. Tests of the side-channel spillway were divided into three general series: (a) tests of the approach and ogee-type spillway weir, (b) tests of the longitudinal channel, and (c) tests of the dispersal bucket and exit area. For these tests, discharges from 5,000 to 70,000 cfs were used, and the tailwater elevation was controlled in accordance with a computed curve (plate 3) furnished by the Pittsburgh District office.

Weir

Original design

13. The sides of the spillway approach inlet were cut on a slope varying from 1 on 1 to 1 on 1-1/2 and had no upstream flare. The weir section was 260 ft in length. Design shape of the spillway downstream from the crest conformed to the parabolic equation $X^{1.85} = 2H_c{}^{0.85}Y$, in which H_c equals the computed spillway design head of 17.0 ft (plate 4). Upstream from the crest the spillway was shaped to a compound curve of radii of 8.5 and 3.4 ft.

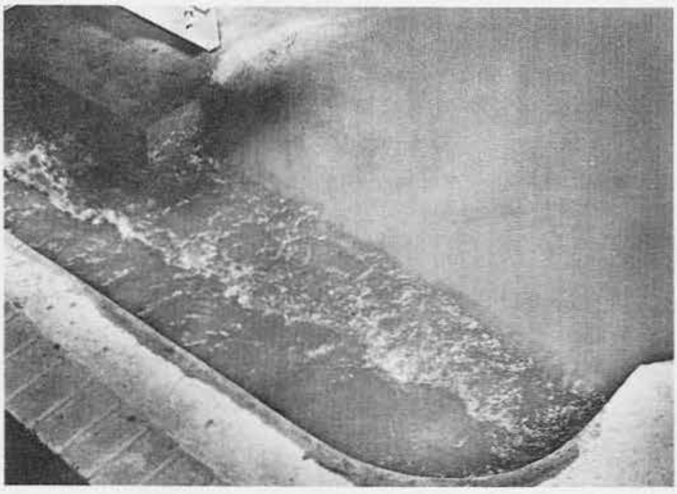

Fig. 3. Flow in original design approach area
Discharge, 70,000 cfs; head, 17.0 ft

14. Initial tests of the approach and weir indicated an excessive amount of turbulence in the approach area (fig. 3). Distribution of flow across the inlet also was very poor. The approach was revised and flared immediately above the weir

crest on a 25-ft radius curve. This eliminated most of the turbulence and provided a better distribution of flow across the weir.

15. The spillway weir was calibrated for heads up to 24 ft. For discharges below 50,000 cfs the model pool was slightly higher than that computed, whereas it was about 1.0 ft lower at a discharge of 80,000 cfs. Plate 5 shows the spillway rating curves as computed and as determined on the model. Also shown are the coefficient curves based on model data and computed from the formula $Q = CLH^{3/2}$, in which

Q = discharge in cfs
C = coefficient of discharge
L = measured length of spillway crest
H = measured head on spillway crest.

16. The coefficient of discharge decreased for discharges over 60,000 cfs, as may be noted from plate 5. This was caused by submergence of the spillway crest by backwater in the side channel. A study of plates 6-9 will show that as the discharge increased, the roller along the left bank of the spillway bucket increased in size and for flows in excess of 60,000 cfs tended to submerge the weir, thus decreasing the efficiency.

Revised design

17. During the course of the study, the Office, Chief of Engineers suggested that these tests be made on an alternate design with the weir shaped for a head of 12.0 ft instead of 17.0 ft. The revised weir (plate 10) was installed and the tests made on the original design were repeated.

18. Results of the tests of the revised design indicated very little difference in the hydraulic actions of the two designs. The effect of submergence was similar to that obtained on the original design. To study the effect of more complete submergence, the head on the crest was arbitrarily

increased above 17 ft, the maximum expected at East Branch Dam (plate 11).

19. Decrease of the design head increased the spillway capacity at high flows about 3 per cent over that of the original crest section (plate 5). This permitted the crest length to be reduced by 10 ft, to 250 ft. Pressures recorded for this design indicated low positive pressures for all discharges, the maximum being a pressure of 40.0 ft for a head of 24.4 ft. Small negative pressures were measured near the crest for flows of 50,000 and 70,000 cfs; no negative pressures occurred for heads of 20.0 and 24.0 ft.

Tests of Longitudinal Channel

20. The longitudinal channel is described in paragraphs 1 and 2 and shown in fig. 1. It had a 7.5-ft raised step at the upper end and terminated in a dispersal bucket. The grade varied from 2.86 per cent immediately downstream from the weir to 12 per cent near the bucket. The channel will be concrete lined throughout with side slopes of 4 vertical to 1 horizontal.

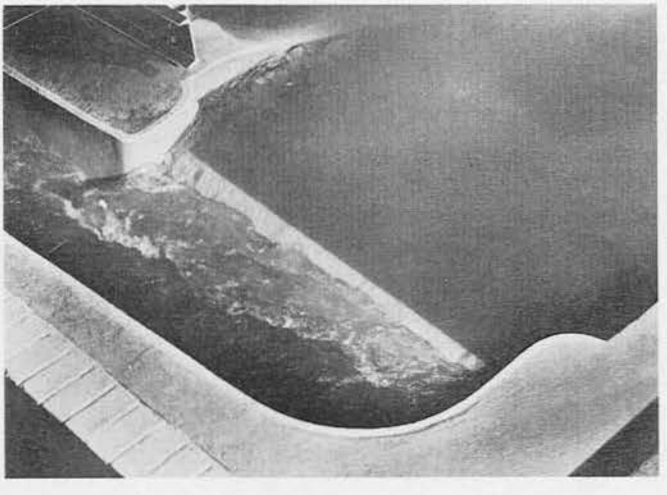

Fig. 4. Flow in revised design approach area
Discharge, 70,000 cfs; head, 17.0 ft

21. Conditions in the channel were satisfactory for all flows; however, considerable turbulence was initially present in the upstream end. This turbulence was largely alleviated by changing the right-angle junction of the right spillway abutment with the chute wall to a curve with a 12.5-ft radius (compare figs. 3 and 4).

Further attempts were made to reduce the turbulence in the upstream end of the channel by raising the floor of the spillway bucket to eliminate the 7.5-ft step, and by increasing the height of the step. Elimination of the step resulted in more irregular flow in the chute and an increase in the amount of turbulence. Increasing the height of the step had no appreciable effect on the flow in the channel.

22. Water-surface profiles were measured along the center line of the channel for the conditions described above. Plates 12 and 13 show the water-surface profiles obtained for the various flows tested. It will be noted that for the higher discharges the flow lines obtained on the upper end of the model channel were higher than the computed flow lines. It is believed that this was caused by the turbulence in the channel and by the "braiding" action of flow.

23. A complete check of all factors that might affect the water-surface elevation was made to assure the accuracy of the water-surface profile obtained. No errors were discovered and, as the results agreed very closely with those obtained on a similar model study* made by the Binghamton District, Corps of Engineers, it is believed that the water-surface profiles as shown are correct.

Tests of Dispersal Bucket

24. Some means of dispersing the energy of the flow, other than the usual type stilling basin, had to be devised because of the high

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* U. S. Corps of Engineers, Binghamton District. Hydraulic Model Tests of the Arkport Side Channel Spillway and Outlet Structure. 30 June 1939.

velocities encountered in the longitudinal channel and the low tailwater depths. Topographically the area downstream of the dam consisted of a very steep slope on the left bank of the stream and a low area of inhabited land on the right bank, which made it necessary that the main flow be directed down the center of East Branch River to prevent undermining the left bank or inundating the right. Foundation conditions also were a limiting factor in designing the dispersal device.

25. The investigation of the dispersal device included variation in shape, size, alignment of side walls, and lip slope. A complete series of flows was tested for each type dispersal device investigated. Bottom velocities were measured on those designs for which flow conditions appeared satisfactory. The exit area was molded in cement mortar as it was believed that velocity observations were sufficient to indicate areas of potential scour and the relative effectiveness of various basin designs.

Type A bucket

26. The bucket originally proposed was similar in pattern to that used for Tunnel No. 2 at Fontana Dam on the Little Tennessee River. This bucket, type A (plate 14), was of a spoon-shaped flip design, with a bottom elevation of 1530.0, a lip height of 15 ft, and a slope on the upstream face of the lip of 1 on 1.

27. Flow characteristics of the type A dispersal bucket were satisfactory for low discharges, but for high discharges the flow impinged directly upon the point of low ground on the right bank as shown by plate 15. This characteristic was very undesirable because of private property developments on this land. At high flows a large eddy was present just

upstream of the point at which the dispersal bucket intersected the river.

Type A1 bucket

28. A spoon-shaped trough was added to the left side of the bucket in this design which was a modification of type A. The bottom elevation was maintained at 1530.0 with a lip height of 15.0 ft and a 1-on-1 slope on the upstream end of the lip.

29. The type A1 bucket as originally installed caused part of the flow to be directed onto the slope of the left bank of the stream below the dispersal bucket. This was highly undesirable as it would cause undercutting of the bank, thus endangering the entire dispersal bucket. Consequently, several alignments of the left wall of the bucket were tested until it was determined that a straight left wall (plate 14) provided most nearly the desired flow conditions. This design produced some improvement in dispersal of flow, although spray still fell on the left bank of the stream at high discharges and the concentration of flow on the right bank was still too great (see plate 16).

Type A2 bucket

30. This design consisted of an oval-shaped bucket with a bottom elevation of 1530.0 and the downstream end curved on a radius of 39 ft with a lip height of 15 ft (plate 14).

31. Flow observations and velocity distribution measurements indicated that although the distribution of flow downstream from the bucket was the best observed for the type A buckets, too much of the discharge was allowed to fall on the left bank below the dispersal bucket (plate 17). Flow still impinged too strongly upon the right bank.

Type B bucket

32. This bucket was of the chute type with the bottom at the upper end molded to an 80-ft vertical curve having a minimum elevation of 1530.0. The downstream end curved upward on a 58-ft radius with a lip height of 8 ft (plate 14).

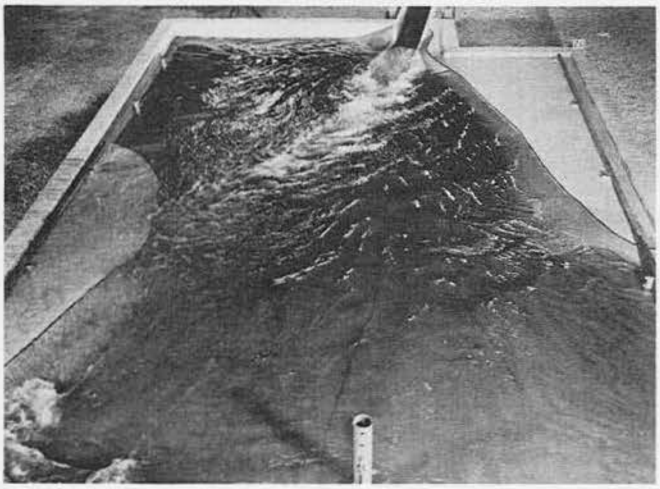


Fig. 5. Type B bucket flow characteristics
Discharge, 70,000 cfs; tailwater, 1549.9

33. Observation of bucket action during various discharges disclosed that flow was too concentrated and indicated that scour immediately downstream from the bucket would be excessive. Fig. 5 shows flow characteristics of this design for the maximum discharge. No other tests were made on this bucket.

Type C bucket

34. This bucket was similar in design to type B, except that the lower side walls were flared on a 260.0-ft radius and three 8.0-ft-high deflector blocks were equally spaced across the lower end. Previous tests on similar models had shown that for such a design the concentration of flow at low discharges would be too great. Also it was apparent that the flare of the walls would cause too much water to fall on the left bank. Therefore, it was not deemed necessary to test this design.

Type D bucket

35. Type D was an attempt to combine the desirable features of

types A and A2. This consisted of eliminating the protruding point in the center of the lower end of the type A buckets and placing the lip at an angle to the center line of the chute. Plate 18 shows details of this bucket.

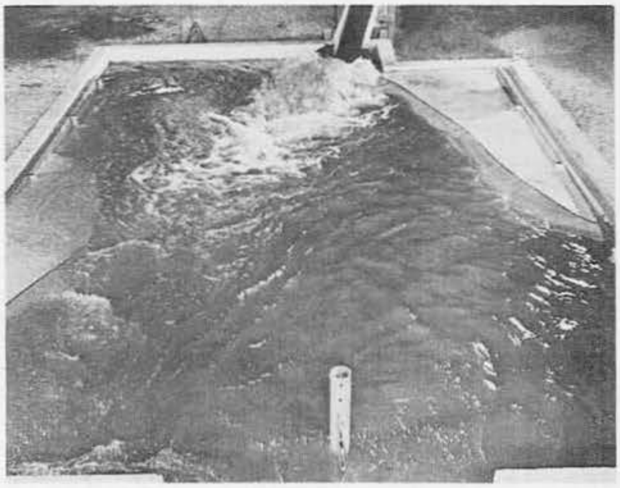


Fig. 6. Flow in type D bucket
Discharge, 70,000 cfs;
tailwater, 1598.8

36. As in previous tests, observations indicated satisfactory conditions for low discharges but an excessive amount of water was directed onto the right bank at high flows (fig. 6).

Type D1 bucket

37. The type D1 bucket was identical to type D except that the left wall was curved inward at the lower end on a radius of 120 ft.

38. It was noted that water fell on the slope of the left bank during initial tests of this design with the left wall at the original design elevation of 1545.0. The wall was then raised until the flow was deflected away from the slope. The optimum height of the wall was determined to be 10 ft above that of the original design or at elevation 1555.0 ft (plate 18). Some scour would probably occur immediately below the bucket, judging from the magnitude of the velocities in the exit area, but it should not endanger any of the structures. Piezometers were installed in the lower end of the bucket (plate 19) and pressures measured for the range of flows. These measurements are listed in table 1. For

the maximum discharge pressures decreased from a maximum of 88 ft at the base to a minimum of 8 ft near the top of the lip. Water-surface profiles along the center line of the channel and into the exit area are shown on plates 12 and 13. Plates 20-23 show velocity data and current patterns. The lip angle was varied from 30° to 60° to determine the effect of varying the slope of the bucket lip, and visual observations were made of the results. The lip slope of 45° as originally designed gave the most satisfactory results. Additional information was desired by the Pittsburgh District as to the water-surface profile in the dispersal bucket for a flow of 5,000 cfs. This information was necessary in order to provide for an overflow weir along the trailing edge of the bucket if no spray action were present to deflect the water from the downstream toe. Tests made with this flow (fig. 7) indicated that some type of weir would probably be necessary for these low flows. Information also was requested by the Pittsburgh District as to the discharge required for flow to sweep out of the dispersal bucket. These tests indicated that flow swept out of the bucket at slightly over 10,000 cfs on rising pool stages; on the falling stage, the discharge dropped to approximately 9,000 cfs before it ceased to sweep out of the bucket (fig. 8).

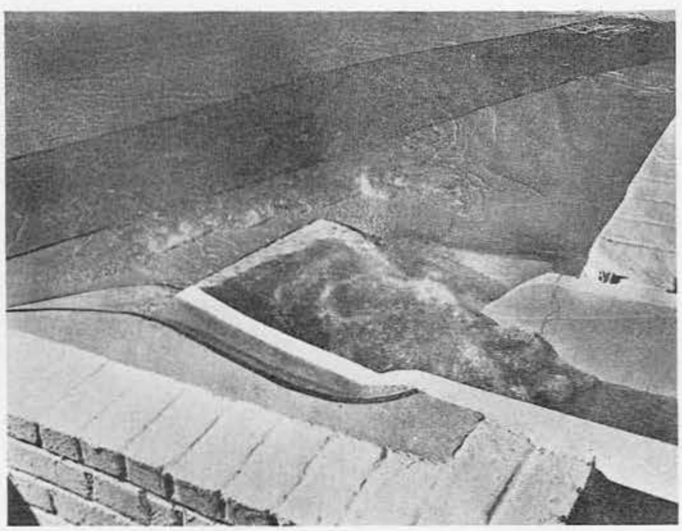
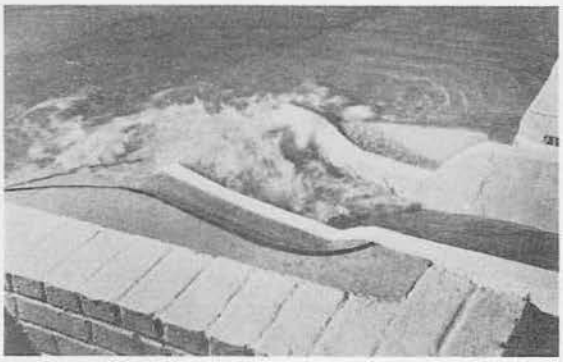
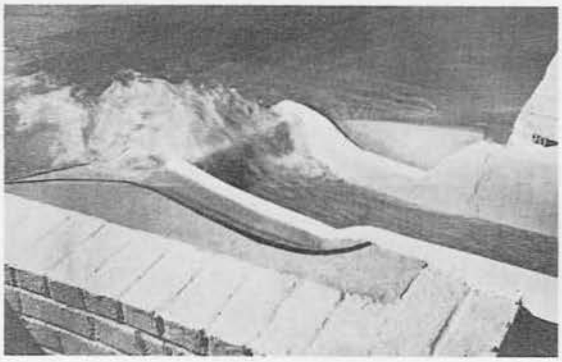


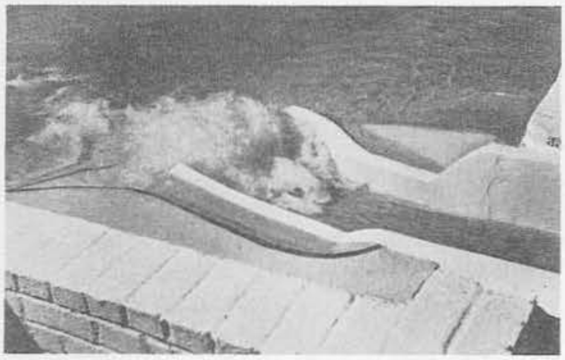
Fig. 7. Flow in type D1 bucket
Discharge, 5,000 cfs; tailwater 1531.0



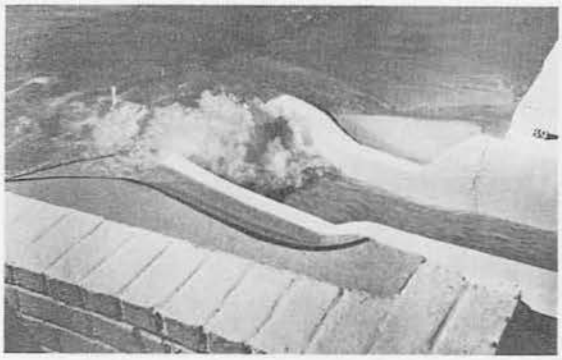
Discharge, 10,000 cfs;
rising pool stage



Discharge, 10,000 cfs;
falling pool stage



Discharge, 10,500 cfs;
rising pool stage



Discharge, 8,900 cfs;
falling pool stage

Fig. 8. Flow in type D1 bucket at three discharges

Type E bucket

39. This bucket was a modification of type A1, in which the radius defining the right wall was increased in an attempt to eliminate some of the objectionable spray and the left wall was curved slightly inward near the lip of the bucket (plate 18). The height of the left wall necessary to protect properly the left bank was to be determined by the model tests.

40. Tests of this design with the left wall at elevation 1545.0 clearly indicated that no protection was afforded the left bank (fig. 9). It was determined from tests that it was necessary to raise this wall 25.0 ft (to elevation 1570.0) in order to divert the flow from the left

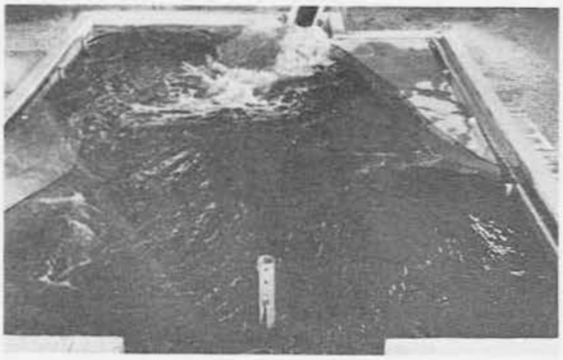


Fig. 9. Type E bucket; left wall elevation, 1545.0

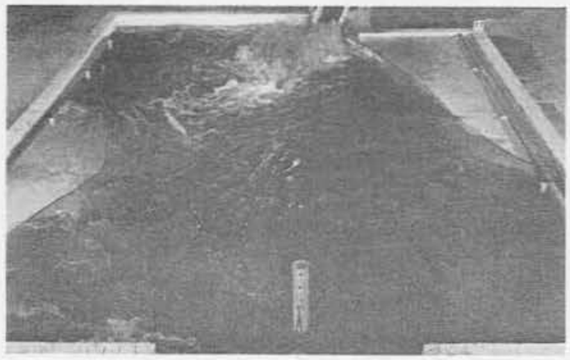


Fig. 10. Type E bucket; left wall elevation, 1570.0

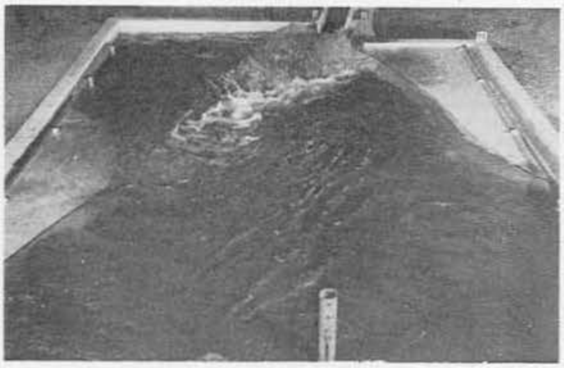


Fig. 11. Type E1 bucket; left wall elevation, 1560.0

Flow characteristics in types E and E1 buckets with left wall at three different elevations. Discharge, 70,000 cfs; tailwater, 1549.8

bank below the bucket. Although the left bank was as well protected as with type D1 bucket installed, the flow was not as evenly distributed and more objectionable spray was noted for the higher flows (fig. 10). Also the cost of construction would be greater than for the type D1 bucket.

Type E1 bucket

41. This design was an attempt to improve upon the action of the type E bucket, to which it was similar except that the left wall was straight and at elevation 1570.0 (plate 18). Tests were conducted with this wall at varying elevations and it was found necessary that it be at

least at elevation 1560.0 in order to afford protection to the left bank. No additional protection was gained by increasing the height of the wall. The flow characteristics were similar to those of type E (compare figs. 9, 10 and 11).

PART III: NARRATIVE OF TESTS -- OUTLET WORKS

42. Tests of the outlet works were divided into two general phases, (a) tests of the intake structure and conduit, and (b) tests of the stilling basin and exit area. Discharges up to 5,000 cfs were used and the tailwater was controlled in accordance with the computed tailwater curve (plate 3) as in the tests of the side-channel spillway.

Tests on Intake Structure and Conduit

Original design

43. The intake structure proposed for East Branch Dam (plate 2) consisted of a curved intake leading into two rectangular passages, flow through which will be controlled by vertical slide gates. Low-water flows will be discharged by means of two 27-in. discharge lines extending through the intake structure. Flow will be conveyed from the rectangular passages through a transition section into a circular conduit (fig. 12).

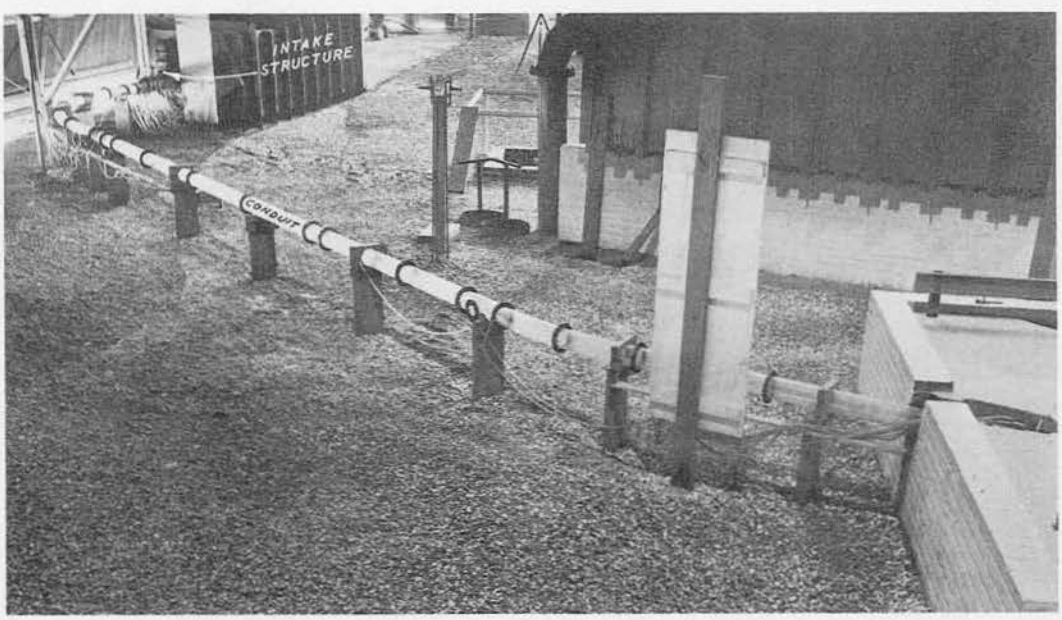


Fig. 12. Outlet works model showing conduit and intake structure

This conduit is to be 10 ft in diameter and approximately 1250 ft in length having two horizontal curves of 250-ft radius at the upper and lower ends, respectively. At the lower end of the conduit, flow will pass through a short transition from circular to horseshoe shape and then into the stilling basin.

44. Observations indicated that flow characteristics were satisfactory for nearly all operating conditions except as noted in the following paragraph. Pressures recorded throughout the intake structure and conduit were for the most part positive. However, a negative pressure of -21.4 ft was recorded in the vicinity of the downstream nose of the separation pier for operating conditions with one gate at full opening and a discharge of 3,950 cfs (plate 24 and tables 2-5). The stage-discharge relations for both full and partial gate openings are shown on plate 25.

45. While obtaining the discharge relation curves for various gate openings it was noted that a fluctuating flow was set up in the conduit for a discharge of 2,000 cfs or greater, with the left gate completely closed and the right gate open approximately 10 ft. The high-velocity flow through the partly-opened gate tended to move in a spiral path as it passed through the transition section (fig. 13) and the entire conduit was filled with a mixture of water and air. The horizontal curve immediately below the transition section apparently aggravated these turbulent conditions, so that large air pockets were formed below the first curve and passed along the conduit (fig. 14) and into the stilling basin. These air pockets caused the pressure in the conduit to fluctuate about 6.0 ft and formed a series of waves in the stilling basin (fig. 15). A reversal

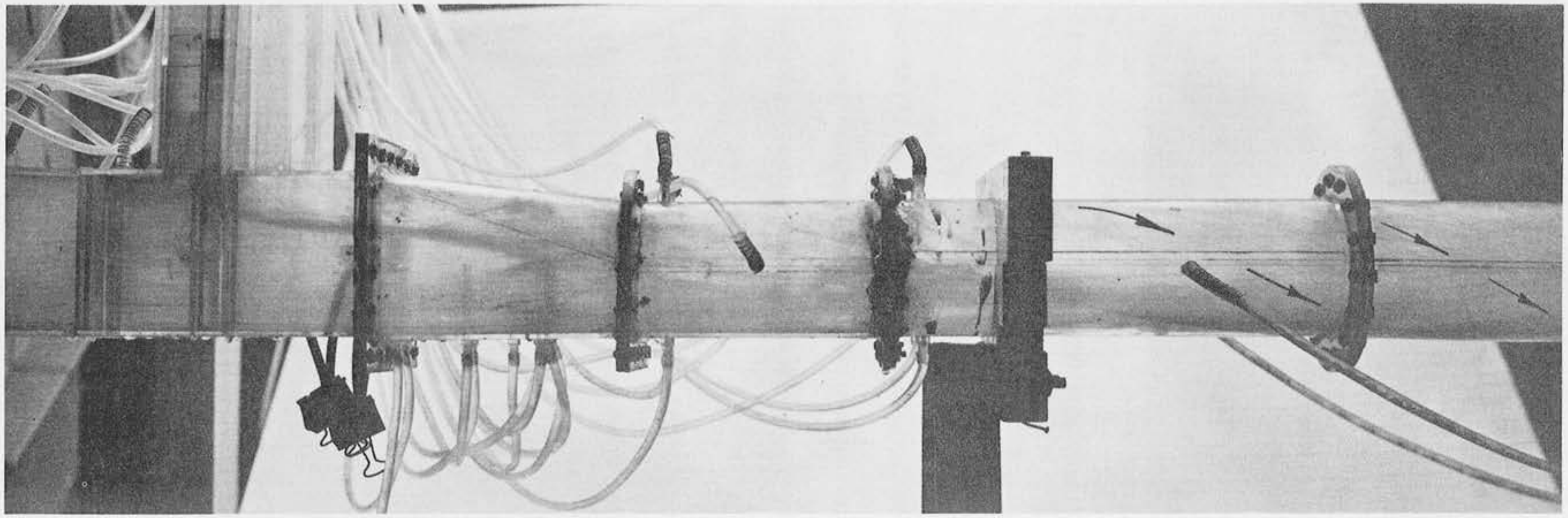


Fig. 13. High-velocity flow through partly opened gate tended to spiral in transition section. Discharge, 2,500 cfs; pool elevation, 1683.0. Left gate closed, right gate open 10 ft

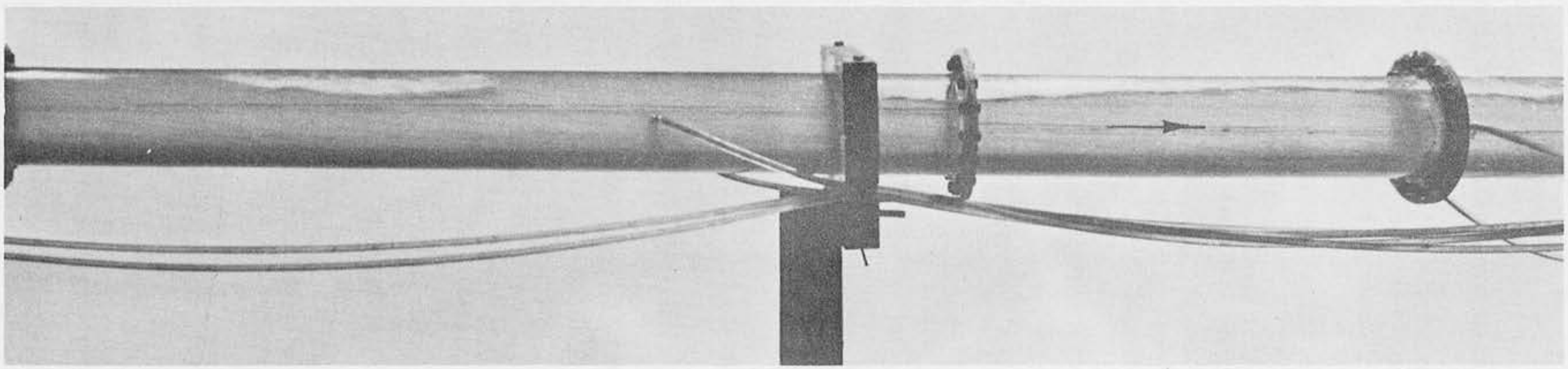


Fig. 14. For same conditions, air pockets formed below first curve and passed along conduit to stilling basin

Fig. 15. Waves in stilling basin formed by air bubbles resulting from right gate being open 10 ft. Discharge, 2,500 cfs

of gate openings reduced the size of the air pockets to such an extent that they were not objectionable. The undesirable features described earlier in this paragraph did not occur at any other operating condition.

Addition of discharge line

46. After completion of tests on the original design the Pittsburgh District requested that the outlet of one of the low-water discharge lines be added to the model and the pressures remeasured in the vicinity thereof. Accordingly, a line was added to the left side of the intake structure and the tests repeated. There were no changes in flow conditions and pressures from those obtained for the original condition.

Revision to the Intake Structure and Transition

Type A transition

47. The type A transition extended from station 6+03.5 to station 6+45.0 and provided a more gradual transition from the rectangular passages to the circular conduit than did the original design. The separation pier was elliptical in shape with a sloping downstream end so as to provide a more gradual change in cross-sectional area (plate 26). This transition proved unsatisfactory as it did not alleviate any undesirable conditions and reduced the maximum discharge approximately 400 cfs.

Type B transition

48. The type B transition was similar in design to transition A, except that the downstream end of the separation pier was reshaped so as to provide more cross-sectional area in this region (plate 26). This transition improved the flow conditions throughout and materially reduced the size of the air pockets. The negative pressures were raised to a maximum of -19 ft. Representatives of the Pittsburgh District viewed the operation of the model with this transition installed and decided that the design was unsatisfactory because the low-water flow would impinge directly upon the side of the pier and possibly cause damage.

Type C transition

49. The type C transition consisted of revising the lower half of the original design between stations 6+23.5 and 6+45.0 so that the change from horseshoe shape to circular was more gradual (plate 27). This revision apparently increased the spiral action of the flow for partial gate openings and worsened the undesirable conditions previously noted.

Types D and E transitions

50. These revisions consisted of changing the shape of the lower end of the separation pier below station 6+03.5 to an ellipse and a circle, respectively. Neither revision improved flow conditions.

Recommended intake structure and conduit

51. None of the transition revisions improved the flow conditions with a 10-ft gate opening on the right passage and with the left gate completely closed over those obtained with the original transition.

Positive pressures existed throughout for both gates at full opening. Therefore, it is recommended that the original transition be retained with the following additions.

52. Addition of center vane in transition. As previously noted the undesirable flow conditions encountered were believed to be caused partly by the spiral action of the flow in the transition and upper end of the conduit. Therefore, tests were made with a 1.0-ft-wide by 1.0-ft-high vane added along the center line of the base of the original transition from the end of the separation pier to the upper end of the conduit, in an endeavor to break up this spiral. After several tests the vane was raised to 2.0 ft in height and another series of tests made. The formation of air pockets was eliminated for all operating conditions except those with the right gate open approximately 11.0 ft and the left gate completely closed. Negative pressures also were reduced to a maximum of -13.4 ft (table 6). Tests were made with this vane installed in the type C transition but the flow conditions were not as satisfactory as those in the original transition.

53. Conduit revisions. Several revisions were made to the conduit in an attempt to improve flow conditions. The transition section on the lower end of the conduit was removed and a straight section inserted. This revision had no effect on the undesirable flow conditions. The slope of the conduit was varied as shown on plate 28. These changes in grade tended to vary the interval between the formation of the air pockets but did not improve flow conditions. An attempt was made to reduce the air pockets by installing various diameter vents at several different locations along the conduit. Vents installed in the lower section of the conduit had

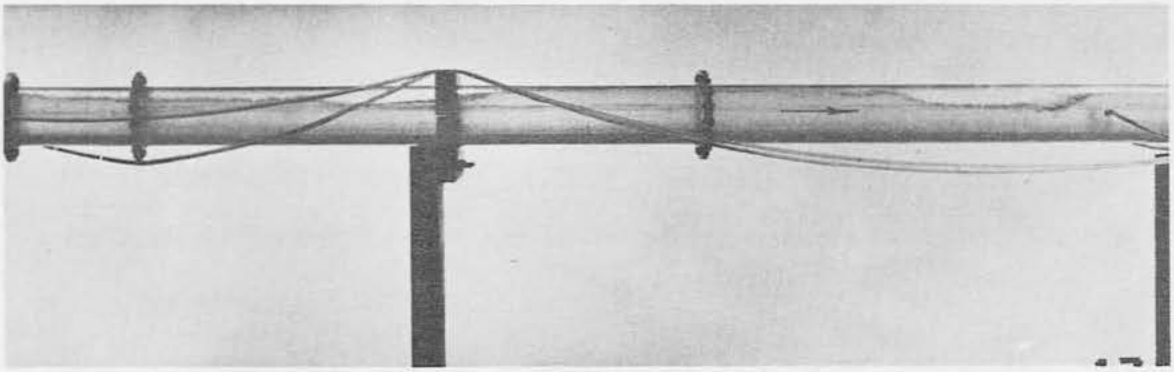


Fig. 16. Flow in conduit with 5-ft-diameter vent installed. Discharge, 2,500 cfs; pool elevation, 1683. Right gate open 10 ft

no effect on the air pockets, and those installed immediately below the transition section tended to aggravate the undesirable flow conditions. Installation of a 5.0-ft-diameter vent in the vicinity of station 12+75 produced the most marked effect on the air pockets. With this vent installed the time interval between formation of pockets was greatly increased but the size of the pockets was also increased (fig. 16).

54. Addition of a 1.0-ft-wide by 2.0-ft-high vane along the center line of the original transition section produced the best flow conditions of all revisions enumerated in the foregoing paragraphs. Therefore, it is recommended that the original intake structure and conduit with the addition of this vane be incorporated in the final design.

Tests on Stilling Basin

55. The stilling basin as originally designed was of the hydraulic-jump type with an over-all length of 156 ft. The basin consisted of a stepped approach apron and a stepped end sill with a row of baffles across the center section. Concrete training walls flanked either side

of the basin with the walls extending approximately 44 ft below the end sill in the initial design. The exit area downstream from the end sill was paved for a distance of about 100 ft.

56. Flow conditions in the original basin were satisfactory for all conditions of discharge. Flow was spread evenly over the exit area and maximum bottom velocities were approximately 10 ft per second for a flow of 5,000 cfs. The scour was not excessive for any flow and occurred far enough below the exit apron so as not to endanger the structure (plates 29-31). Tailwater elevations were varied and observations indicated that the best flow conditions were obtained with the computed tailwater (plate 32).

57. It was desired to shorten the left training wall as much as possible for purposes of economy in construction. Therefore, a series of tests was made in order to determine the effect that shortening this wall would have on the flow characteristics. The left training wall was shortened by 10.0 ft and a series of flow observations made. The variation in flow characteristics from that of the original design was so slight that no data were obtained for this design. The left wall was then shortened by 20.0 ft and the tests repeated. Scour was increased approximately one foot, and the velocity pattern remained essentially the same (plates 33-35). An additional 20.0 ft was then removed from the left wall, thus placing the end of the wall at the top of the end sill (fig. 17). This change increased the scour below the exit area and the maximum velocity by approximately 2.0 ft, but the over-all change in flow conditions was so slight as to be negligible (plates 36-38).

58. A series of tests was conducted with all baffle piers removed

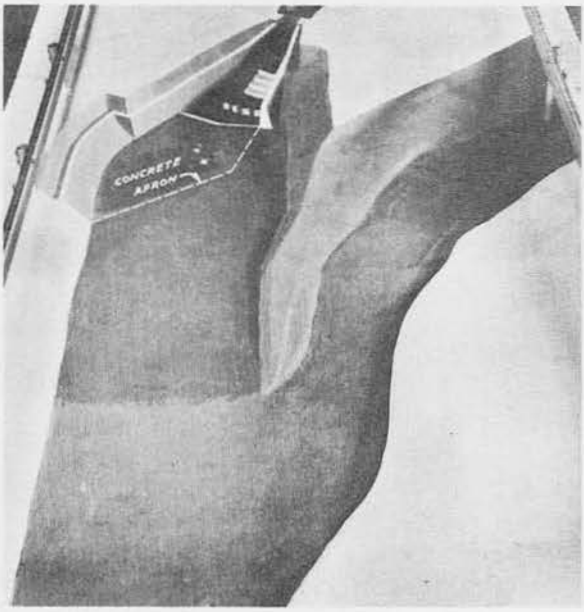


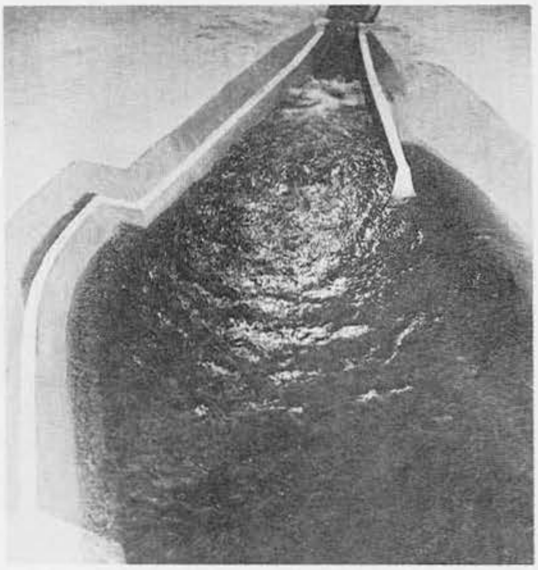
Fig. 17. Recommended stilling-basin design with left training wall terminated at end sill

from the apron, both with original conditions and with the left wall cut 40 ft, in order to determine the effect of the baffle piers on flow conditions in the stilling basin. Flow conditions were very unsatisfactory for both conditions. With computed tailwater elevations no jump was formed and the end sill performed all the energy dissipation with a resulting unstable condition of flow in the exit area. However, the scour in the exit area was not excessive, being only about 3 ft more than for the original design (plates 39-41). It was necessary to raise the tailwater elevation approximately 3 ft higher than the computed elevation for flow of 5,000 cfs in order to obtain an adequate jump (plate 32). Velocities over the end sill also were measured with the tailwater varied (plate 42). No velocities could be measured for a discharge of 5,000 cfs as the turbulence of flow over the end sill was such as to preclude the possibility of accurate pitot tube measurements.

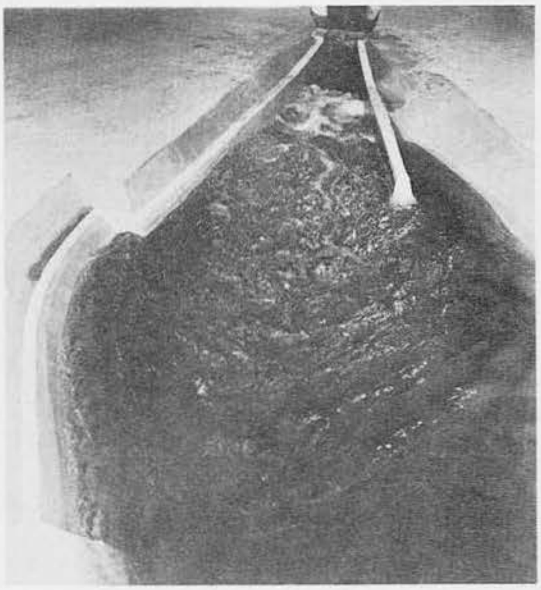
59. Investigation of the effect of the baffle piers on flow conditions was continued by changing the location of the existing row of piers to a point 2.0 ft downstream from the original position. Observations of flow revealed no change from the flow characteristics observed in the original design. Scour tests indicated that relocation of the baffles produced a scour similar to that caused by the original design (plates

43-45). An additional row of baffles was next added to the original design and flow observations and velocity measurements made. Results of these tests (plates 46-48) indicated that the addition of a second row of piers did not improve flow conditions in the basin.

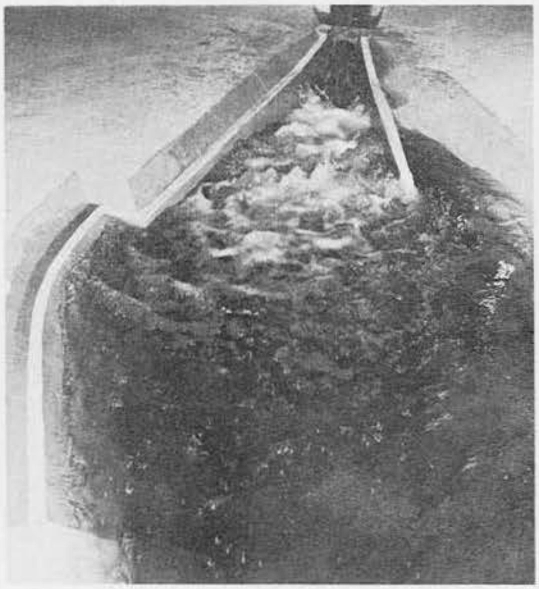
60. Tests of the stilling basin indicated that the length of the left training wall was immaterial and that the baffle piers were required for formation of a good hydraulic jump in the basin. It was recommended, therefore, that the original design of the stilling basin with the left wall terminated at the end sill be adopted (fig. 18).



Discharge, 2,500 cfs;
tailwater, 1528.5



Discharge, 3,500 cfs;
tailwater, 1529.5



Discharge, 5,000 cfs;
tailwater, 1531.0

Fig. 18. Flow conditions in recommended design stilling basin

Tests of Slide Gates

61. The original service gates consisted of two vertical sliding service gates 3 ft 4 in. wide by 12 ft high. The original gate lip was constructed with a 1-ft radius curve on the upstream edge and a 1.5-on-10 bevel on the bottom (plate 49). Previous experience with vertical slide gates warned that dangerous negative pressures might exist in this area. Accordingly, a 1:12-scale model of one slide gate was constructed and tests were made with various gate openings.

62. Tests of the original gate lip indicated that pressures were most critical near the bottom of the gate on the upstream side (plate 50). Negative pressures well within the cavitation range were recorded in this area for gate openings of 6 and 9 ft (tables 7-8). After analyzing the results obtained on the original gate lip it was apparent that the lower edge of the gate would have to be modified in such a way as to alleviate these negative pressures.

63. Accordingly, a vertical lip approximately 1/2 in. in depth was added along the bottom of the gate (plate 49). This revision completely eliminated all negative pressures (plate 51 and tables 9-10). No further tests were made of the gate lip and it was recommended that this modification be adopted.

PART IV: DISCUSSION OF TEST RESULTS

64. Model tests of the East Branch Dam revealed the performance of the original design of the weir and side channel to be satisfactory. However, an increase in efficiency and an economy in construction cost could be obtained by making several revisions in the original design. Smoother flow was obtained in the inlet channel by flaring the approach channel and the right bank at the upper end of the side channel so as to reduce turbulence in that area. It was determined that the ogee-type spillway weir crest could be shaped for a head of 12.0 ft instead of 17.0 ft. This permitted a reduction of about 10.0 ft in spillway length without affecting the action of the spillway.

65. Small negative pressures were measured on the revised design of the spillway crest for flows of 50,000 and 70,000 cfs, but no negative pressures were encountered for normal operating flows. Occurrence of negative pressures of this magnitude (-5.2 ft maximum) should produce no harmful effects in the prototype. For discharges below 50,000 cfs the model curve for a design head of 17.0 ft showed slightly less efficiency than the computed curve; whereas, for discharges in excess of 50,000 cfs the model curve showed a slight increase in efficiency. For a design head of 12.0 ft and the original spillway crest length the discharge was increased about 3 per cent over that computed for a design head of 17.0 ft for the higher flows. For flows over 60,000 cfs the discharge coefficient decreased due to submergence of the crest by backwater in the side channel. Slight negative pressures existed near the crest for these high flows, indicating that, were it not for this submergence, the coefficient would

have continued to increase.

66. The side channel as originally designed performed satisfactorily for all flows except that the channel lining was overtopped near the upper end for the higher flows, requiring that the elevation of the top of the channel lining be raised. A similar condition was found to exist on the Arkport side-channel spillway as was indicated in a report, dated 30 June 1939, by the Binghamton District, CE, Binghamton, N.Y., subject: "Hydraulic Model Tests of the Arkport Side Channel Spillway and Outlet Structure."

67. It was necessary to construct the dispersal bucket at the location indicated on figure 1 because of foundation conditions. However, it was considered advisable to direct the flow away from the left bank in order to prevent undercutting as a rather steep slope existed to the left of the bucket. Also, it was necessary to direct the flow away from the right bank to prevent the higher flows from inundating a heavily populated point of land in this area. The initial design of the dispersion bucket directed too heavy a concentration of flow upon the right bank of East Branch River and several revisions were required before a design was found that provided the desired dispersal of flow. Small negative pressures were measured on the upper edge of the recommended design of dispersal bucket; however, the magnitude of these pressures (-2.0 ft maximum) was such that they could be disregarded. For low flows in which no spray action would be present in the dispersal bucket, it is suggested that an apron be added to the downstream side of the dispersal bucket lip in order to break the fall of water onto the bottom of the stream.

68. Hydraulic performance of the outlet works was good for all

flow conditions with either one or two gates fully open and with both gates open an equal amount. However, an undesirable series of air pockets was set up in the conduit when operating under a high head and with the left gate fully closed and the right open approximately 10.0 ft. The addition of a vane 1.0 ft wide and 2.0 ft high down the center of the intake transition section tended to alleviate these air pockets. It is recommended also that a prototype gate operating schedule be established such that with a high reservoir pool one gate is not almost open while the other is completely closed. The most desirable method of operation is that of opening both gates equally for all flows.

69. Calibration of the intake structure revealed that the maximum discharge was lowered about 4 per cent from the computed values. Negative pressures as great as -13.0 ft were measured in the intake structure for conditions with one gate fully open and a high reservoir pool. A major revision of the transition section would be necessary to eliminate these negative pressures; therefore it is recommended that the original transition section be retained with the addition of the raised vane extending from the end of the separation pier to station 6+45.

70. No means of improving the performance of the original stilling basin was found. It was determined, however, that the left training wall could be shortened 40.0 ft without affecting basin action. Better flow conditions were obtained by the use of baffle piers, as the basin elevation was too high to permit good jump formation without piers. However, the velocities and scour patterns changed very little regardless of whether or not baffle piers were used.

TABLES

Table 1

DISPERSAL BUCKET PRESSURES

Type D1 Bucket

Piez. No.	Piez. Zero	Q = 70,000 cfs TW = 1549.8	Q = 50,000 cfs TW = 1546.2	Q = 25,000 cfs TW = 1540.2	Q = 10,000 cfs TW = 1534.2	Q = 5,000 cfs TW = 1531.0
1	1530.0	60.0	46.0	14.0	5.0	20.0
2	1535.0	57.0	39.0	4.0	3.0	15.0
3	1540.0	35.0	19.0	-1.0	1.0	10.0
4	1544.0	8.0	2.0	-1.0	0.0	6.0
5	1530.0	77.0	67.0	47.0	31.0	20.0
6	1535.0	88.0	78.0	40.0	13.0	15.0
7	1540.0	57.0	42.0	11.0	2.0	20.0
8	1544.0	16.0	9.0	-2.0	-2.0	6.0
9	1530.0	67.0	58.0	40.0	27.0	20.0
10	1535.0	59.0	52.0	34.0	16.0	15.0
11	1540.0	40.0	33.0	15.0	5.0	10.0
12	1544.0	15.0	11.0	2.5	0.0	6.0

NOTE: Pressures are recorded in prototype feet of water.
Discharges are recorded in cfs.
Tailwater elevations are recorded in feet msl.
Locations of piezometers are shown on plate 19.

Table 2

INTAKE PRESSURES

Piez. No.	Piez. Zero	Two Gates Open 12 Ft: Discharge = 5,000 Pool Elev = 1722.0	Two Gates Open 12 Ft: Discharge = 3,500 Pool Elev = 1626.0	Two Gates Open 12 Ft: Discharge = 2,500 Pool Elev = 1583.0	One Gate Open 12 Ft: Discharge = 3,950 Pool Elev = 1714.0	One Gate Open 12 Ft: Discharge = 3,500 Pool Elev = 1675.0	One Gate Open 12 Ft: Discharge = 2,500 Pool Elev = 1610.0
1	1551.00	157.00	74.00	29.00	134.00	98.00	46.00
2	1550.00	144.00	68.50	26.50	165.00	126.00	62.00
3	1549.00	138.00	65.00	26.00	82.00	109.00	27.00
4	1548.00	134.50	62.00	25.00	167.00	128.00	63.00
5	1547.00	132.00	61.00	25.00	59.00	43.00	18.50
6	1546.00	130.00	60.50	26.00	50.00	38.00	16.50
7	1545.00	126.00	59.50	25.00	38.00	29.00	13.00
8	1544.00	118.00	56.00	25.00	17.00	14.00	5.00
9	1543.00	109.00	55.00	24.50	3.00	2.00	0.00
10	1537.00	149.00	78.00	39.00	-1.00	5.00	40.00
11	1537.00	134.00	70.00	34.00	54.00	41.50	23.50
12	1537.00	123.00	64.00	32.00	27.00	22.00	13.00
13	1537.00	115.00	60.00	30.00	9.00	8.00	5.00
14	1537.00	113.00	59.00	29.00	4.00	5.00	4.00
15	1537.00	111.00	57.50	28.00	-6.00	-4.00	-1.00
16	1537.10	111.90	57.40	27.90	-7.10	-5.10	-1.60
17	1537.20	118.70	60.70	29.25	6.75	5.25	2.75
18	1541.00	112.00	57.00	25.50	15.00	12.00	5.00
19	1540.00	115.00	57.00	26.50	20.00	14.00	7.00
20	1536.23	119.77	62.27	30.77	26.77	20.77	12.27
21	1533.25	124.75	66.75	34.25	30.75	24.75	15.75
22	1531.00	129.00	69.00	37.00	30.00	25.00	17.00
23	1531.00	129.00	69.00	37.50	28.00	22.00	16.00
24	1536.17	122.83	63.83	31.33	43.83	31.83	17.83
25	1536.17	122.83	62.83	31.33	40.83	32.83	16.83
26	1541.00	108.00	51.00	23.50	55.00	39.00	20.00
27	1540.18	108.82	52.82	24.82	53.82	39.82	19.82
28	1538.82	109.18	54.18	26.18	51.18	40.18	19.18
29	1535.52	109.48	56.48	28.98	53.48	41.48	21.48
30	1532.25	105.75	58.75	31.25	58.75	46.75	25.75
31	1531.00	108.00	59.00	32.00	60.00	49.00	28.00
32	1536.38	123.62	62.62	32.12	18.62	14.62	7.62
33	1536.38	123.62	63.12	31.12	16.62	13.12	6.62
34	1536.38	113.62	58.62	29.12	-7.38	-4.38	-1.38
35	1536.38	107.62	55.12	27.12	-21.38	-15.38	-6.38
36	1536.38	108.62	55.62	28.12	-15.38	-10.38	-3.38
37	1536.38	122.62	62.62	31.62	17.62	13.62	6.62
38	1536.38	112.62	57.62	29.62	17.62	13.62	6.62
39	1536.38	105.62	54.62	27.12	18.62	13.62	6.62
40	1536.38	109.62	57.62	30.12	18.62	13.62	6.62
41	1537.00	110.00	60.00	30.00	-11.00	13.00	6.00
42	1537.00	116.00	56.00	28.00	17.00	-8.50	-2.00

NOTE: Pressures are recorded in prototype feet of water.
Discharges are recorded in cfs.
Pool elevations are recorded in feet msl.
Locations of piezometers are shown on plate 24.

Table 3

CONDUIT PRESSURES

		Two Gates Open 12 Ft			One Gate Open 12 Ft		
Piez. No.	Piez. Zero	Discharge = 5,000 Pool Elev = 1722.0	Discharge = 3,500 Pool Elev = 1626.0	Discharge = 2,500 Pool Elev = 1583.0	Discharge = 3,950 Pool Elev = 1714.0	Discharge = 3,500 Pool Elev = 1675.0	Discharge = 2,500 Pool Elev = 1610.0
1	1535.88	105.12	55.12	28.12	63.12	51.12	26.12
2	1535.88	106.12	55.62	27.62	63.12	50.62	26.12
3	1535.52	102.48	52.48	27.48	66.48	52.48	26.98
4	1535.52	95.48	49.48	25.48	61.48	49.48	24.48
5	1535.21	88.29	45.79	23.79	57.79	45.29	23.79
6	1535.21	89.79	62.29	23.79	57.79	45.79	23.79
7	1534.91	89.59	46.59	24.09	58.09	46.09	23.59
8	1534.91	88.09	45.09	23.09	56.09	44.59	23.59
9	1534.54	83.46	42.46	21.46	53.46	42.46	22.96
10	1534.54	82.46	41.51	21.46	52.46	41.46	21.46
11	1534.41	79.59	40.09	20.59	50.59	40.09	20.59
12	1534.41	91.59	41.59	21.09	51.59	41.09	21.09
13	1534.28	80.72	40.72	20.72	50.72	40.22	20.72
14	1534.28	79.72	40.22	20.72	50.72	40.72	20.72
15	1534.11	75.89	38.39	19.89	48.89	38.89	19.89
16	1534.11	75.89	38.89	19.89	48.89	38.39	19.89
17	1533.10	61.90	30.90	15.90	39.90	30.90	16.40
18	1533.10	62.90	31.40	16.40	40.40	31.40	16.40
19	1532.06	47.44	24.94	12.94	30.44	23.94	13.44
20	1532.06	45.94	23.94	12.94	29.94	23.44	12.94
21	1531.02	29.98	15.48	8.98	19.98	14.98	8.98
22	1531.02	39.98	19.98	10.98	25.98	19.98	11.98
23	1530.61	26.89	13.89	8.39	17.39	13.39	8.39
24	1530.61	20.89	10.89	6.39	13.39	10.39	6.39
25	1530.30	19.70	10.20	6.20	12.70	10.20	6.20
26	1530.30	19.70	10.20	6.20	12.70	9.70	6.20
27	1529.64	9.36	5.36	3.36	6.36	5.36	4.36
28	1529.64	7.36	4.36	3.36	4.86	4.36	3.36
29	1534.22	3.88	.28	-0.88	No readings - Air in line		----
30	1529.20	No readings	----	----	----	----	----
31	1524.46	13.40	4.54	8.54	10.54	9.54	8.54
32	1533.97	3.53	0.03	-0.97	No readings - Air in line		----
33	1529.00	8.50	5.00	4.00	6.00	5.00	4.00
34	1524.43	14.57	10.57	9.00	11.57	10.07	8.57
35	1533.71	3.79	.29	-1.21	No readings - Air in line		----
36	1520.70	8.30	4.30	3.30	5.30	4.30	3.80
37	1524.41	12.59	10.09	8.59	10.09	8.59	----

NOTE: Pressures are recorded in prototype feet of water.
Discharges are recorded in cfs.
Pool elevations are recorded in feet msl.
Locations of piezometers are shown on plate 24.

Table 4

AVERAGE PRESSURES WITH TWO GATES OPERATING
PARTIAL OPENING

Piez. No.	Piez. Zero	Pressures										
		Gates Full Open Discharge = 5,000 Pool Elev = 1722.0		Gates Open 10' Discharge = 4,500 Pool Elev = 1715.0		Gates Open 8' Discharge = 4,002 Pool Elev = 1714.0		Gates Open 6' Discharge = 3,070 Pool Elev = 1714.0		Gates Open 4' Discharge = 2,045 Pool Elev = 1714.0		Gates Open 2' Discharge = 1,015 Pool Elev = 1714.0
1	1551.0	157.0*	105.12**	152.0*	91.12**	147.0*	71.12**	155.0*	Air**	177.12*	Air**	151.0*
2	1550.0	144.0	106.12	144.0	92.12	146.0	71.12	152.0	Air	168.12	Air	151.0
3	1549.0	138.0	102.48	136.0	89.48	140.0	70.48	151.0	Air	170.48	Air	152.0
4	1548.0	134.50	95.48	132.0	84.48	137.50	65.48	149.50	Air	171.48	Air	152.50
5	1547.0	132.0	88.29	128.0	75.79	137.0	58.79	148.0	Air	171.29	Air	153.50
6	1546.0	130.0	89.79	126.0	77.79	135.0	60.79	147.50	Air	170.79	Air	154.50
7	1545.0	126.0	89.59	123.0	78.09	132.0	60.09	147.50	Air	169.59	Air	155.50
8	1544.0	118.0	88.09	118.0	75.09	128.0	58.09	145.0	Air	168.09	Air	155.50
9	1543.0	109.0	83.46	114.0	71.46	127.0	56.46	147.0	38.96	168.46	Air	157.0
10	1537.0	149.0	82.46	147.0	69.96	153.0	54.46	153.0	18.46	173.46	Air	164.50
11	1537.0	134.0	79.59	134.0	67.09	143.0	52.59	157.0	20.59	170.59	Air	164.0
12	1537.0	123.0	81.59	125.0	69.09	135.0	53.59	153.0	28.59	169.09	Air	163.50
13	1537.0	115.0	80.72	115.0	68.22	126.0	51.72	145.0	26.22	165.72	Air	162.50
14	1537.0	113.0	79.72	74.0	67.72	28.0	52.22	Air	28.22	Air	Air	Air
15	1537.0	111.0	75.89	67.0	64.89	25.0	49.89	Air	32.89	Air	Air	Air
16	1537.10	111.90	75.89	84.90	64.89	24.90	49.89	Air	29.89	Air	Air	Air
17	1537.25	118.75	61.90	93.75	51.90	33.75	40.90	Air	27.40	Air	Air	Air
18	1541.0	112.0	62.90	94.0	52.90	46.0	41.40	Air	29.90	Air	Air	Air
19	1540.0	115.0	47.44	95.0	39.94	48.0	31.94	Air	22.94	Air	-7.06	Air
20	1536.23	119.77	45.94	98.77	38.94	50.77	30.94	Air	21.94	Air	1.44	Air
21	1533.25	124.75	29.98	102.75	24.98	57.75	19.98	3.75	13.98	Air	0.98	Air
22	1531.0	129.0	39.98	105.0	33.98	60.0	25.98	7.0	17.48	Air	4.98	Air
23	1531.0	129.0	26.89	106.0	23.39	60.0	18.39	8.0	13.39	Air	3.89	Air
24	1536.17	122.83	20.89	100.83	17.39	63.83	13.89	Air	9.89	Air		Air
25	1536.17	122.83	19.70	99.83	14.70	65.83	12.70	Air	8.70	Air	2.70	Air
26	1541.0	108.0	19.70	90.0	15.20	66.0	13.20	Air	9.20	Air	2.20	Air
27	1540.18	108.82	9.36	90.82	7.36	65.82	6.36	Air	4.36	Air	2.36	Air
28	1538.82	109.18	7.36	92.58	6.36	67.18	5.36	Air	2.36	Air	1.36	Air
29	1535.52	109.48	3.88	94.68	12.28	66.48	10.78	Air	2.28	Air		Air
30	1532.25	105.75		94.75		68.75		Air		Air		Air
31	1531.0	108.0	13.04	96.0	11.54	70.0	10.54	Air	8.04	Air	7.04	Air
32	1536.38	123.62	3.53	94.62	1.53	34.62	1.03	Air	2.03	Air		Air
33	1536.38	123.62	8.50	93.62	7.0	33.62	6.0	-3.68	3.0	Air	2.50	Air
34	1536.38	113.62	14.57	92.62	12.57	32.62	11.57	-5.38	9.07	Air	7.57	Air
35	1536.38	107.62	3.79	78.62	2.29	15.62	1.29	-0.38	3.79	Air		Air
36	1536.38	108.62	8.30	64.62	5.80	9.62	5.30	0.62	2.80	Air	2.30	Air
37	1536.38	122.62	12.59	93.62	11.09	32.62	10.09	0.12	7.59	Air	6.59	Air
38	1536.38	112.62		90.62		31.62		-0.38		Air		Air
39	1536.38	105.62		78.62		18.62		0.12		Air		Air
40	1536.38	109.62		68.62		8.62		-0.38		Air		Air
41	1537.0	110.62		63.0		40.0		-34.0		Air		Air
42	1537.0	116.0		73.0		21.0		Air		Air		Air

NOTE: Pressures are recorded in prototype feet of water.
Discharges are recorded in cfs.
Pool elevations are recorded in feet msl.

Locations of piezometers are shown on plate 24.
* Intake pressures
** Tunnel pressures

Table 5

AVERAGE PRESSURE WITH ONE GATE CLOSED
PARTIAL OPENINGS

Piez. No.	Piez. Zero	Pressures: Gate Full Open Discharge = 3,950 Pool Elev = 1714.0		Gate Open 10' Discharge = 2,300 Pool Elev = 1714.0		Gate Open 8' Discharge = 2,100 Pool Elev = 1714.0		Gate Open 6' Discharge = 1,590 Pool Elev = 1714.0		Gate Open 4' Discharge = 1,100 Pool Elev = 1715.0		Gate Open 2' Discharge = Pool Elev =
1	1551.0	134.0*	63.12**	145.0*	1.12**	153.0*	-1.88**	157.0*	Air**	162.0*	Air**	
2	1550.0	165.0	63.12	155.0	4.62	155.0	2.12	156.0	Air	160.0	Air	
3	1549.0	82.0	66.48	123.0	5.48	141.0	1.48	153.0	Air	158.0	Air	
4	1548.0	167.0	61.48	155.0	0.48	162.0	Air	162.0	Air	160.0	Air	
5	1547.0	59.0	57.79	108.0	1.79	134.0	-5.21	151.0	Air	160.0	Air	
6	1546.0	50.0	57.79	103.0	7.79	132.0	Air	150.0	Air	161.0	Air	
7	1545.0	38.0	58.09	100.0	9.09	131.0	1.09	149.0	Air	162.0	Air	
8	1544.0	17.0	56.09	90.0	Air	126.0	Air	146.0	Air	160.0	Air	
9	1543.0	3.0	53.46	84.0	10.46	125.0	1.46	147.0	Air	161.0	Air	
10	1537.0	-1.0	52.46	131.0	Air	153.0	Air	173.0	Air	171.0	Air	
11	1537.0	54.0	50.59	111.0	7.59	141.0	Air	157.0	Air	166.0	Air	
12	1537.0	27.0	51.59	99.5	9.59	134.0	Air	153.0	Air	157.0	Air	
13	1537.0	9.0	50.72	86.0	9.22	123.0	Air	146.5	Air	Air	Air	
14	1537.0	4.0	50.72	23.0	9.72	15.0	Air	Air	Air	Air	Air	
15	1537.0	-6.0	48.89	3.0	10.89	2.0	Air	Air	Air	Air	Air	
16	1537.10	-7.1	48.89	-4.1	9.89	-5.40	Air	Air	Air	Air	Air	
17	1537.25	6.75	39.90	-5.25	4.90	0.75	Air	Air	Air	Air	Air	
18	1541.0	15.0	40.40	Air	10.40	Air	Air	Air	Air	Air	Air	
19	1540.0	20.0	30.44	Air	6.94	Air	1.94	Air	Air	Air	Air	Unable to obtain readings at this opening.
20	1536.23	26.77	29.94	Air	9.94	Air	0.94	Air	Air	Air	Air	
21	1533.25	30.75	19.98	7.75	11.98	4.75	1.98	Air	0.98	Air	Air	
22	1531.0	30.0	25.98	11.0	14.98	7.0	5.48	Air	2.98	Air	Air	
23	1531.0	28.0	17.39	10.0	10.39	7.0	3.89	Air	2.39	Air	Air	
24	1536.17	43.83	13.39	Air	7.39	Air	1.89	Air	0.39	Air	Air	
25	1536.17	40.83	12.70	Air	6.70	Air	3.20	Air	1.70	Air	Air	
26	1541.0	55.0	12.70	Air	6.70	Air	3.20	Air	1.70	Air	Air	
27	1540.18	53.82	6.36	Air	4.36	Air	2.86	Air	1.36	Air	Air	
28	1538.82	51.18	4.86	Air	3.36	Air	3.36	Air	1.36	Air	Air	
29	1535.52	53.48	Air	Air	Air	Air	Air	Air	Air	Air	Air	
30	1532.25	58.75		0.75		2.25		Air	Air	Air		
31	1531.0	60.0	10.54	5.0	8.04	4.50		Air	7.54	Air	5.54	
32	1536.38	18.62	Air	Air	Air	Air	Air	Air	Air	Air	Air	
33	1536.38	16.62	6.0	Air	4.0	Air	4.06	Air	1.50	Air	Air	
34	1536.38	-7.38	11.57	Air	11.57	Air	8.07	Air	6.57	Air	5.57	
35	1536.38	-21.38	Air	Air	Air	Air	Air	Air	Air	Air	Air	
36	1536.38	-15.38	5.30	Air	3.30	Air	2.30	Air	5.80	Air	Air	
37	1536.38	17.62	10.09	Air	8.59	Air	7.09	Air	11.09	Air	5.09	
38	1536.38	17.62		Air		Air		Air		Air		
39	1536.38	18.62		Air		Air		Air		Air		
40	1536.38	18.62		Air		Air		Air		Air		
41	1537.0	-11.0		Air		Air		Air		Air		
42	1537.0	17.0		Air		Air		Air		Air		

NOTE: Pressures are recorded in prototype feet of water.
Discharges are recorded in cfs.
Pool elevations are recorded in feet msl.

Locations of piezometers are shown on plate 24.
* Intake pressures
** Tunnel pressures

Table 6

INTAKE PRESSURES

ORIGINAL TRANSITION WITH VANE ALONG CENTER LINE

One Gate Open 12 ft
Discharge = 3950 cfs
Pool Elev = 1714 ft

Piez. No.	Piez. Zero	Pressure
14	1537.0	6.00
15	1537.0	1.00
16	1537.10	1.90
17	1537.25	13.75
18	1541.00	20.00
19	1540.00	22.00
20	1536.23	29.77
21	1533.25	36.75
22	1531.00	40.00
24	1536.17	40.83
25	1536.17	46.83
32	1536.38	21.62
33	1536.38	20.62
34	1536.38	23.62
35	1536.38	-12.38
36	1536.38	-13.38
39	1536.38	20.62
40	1536.38	20.62
41	1537.00	-13.00
42	1537.00	22.00
43	1542.25	1.75
44	1542.75	Air
45	1542.45	Air
46	1541.75	Air
47	1540.50	15.50
48	1541.25	Air
49	1535.50	10.50
50	1533.75	-8.75
51	1532.25	13.75

NOTE: All measurements in prototype units.
Locations of piezometers are shown on plate 24.

Table 7

PRESSURE DATA - ORIGINAL GATE LIP
GATE OPEN 6.0 FT

Piez. No.	Discharge = 3800.0 cfs, Pressure = 124.0 ft, $V^2/2g$ = 24.3 ft, Head = 148.3 ft: Pressure	C	Discharge = 3536.0 cfs, Pressure = 105.0 ft, $V^2/2g$ = 21.1 ft, Head = 126.1 ft: Pressure	C	Discharge = 3237.0 cfs, Pressure = 85.1 ft, $V^2/2g$ = 17.7 ft, Head = 102.8 ft: Pressure	C	Discharge = 2789.0 cfs, Pressure = 61.9 ft, $V^2/2g$ = 13.1 ft, Head = 75.0 ft: Pressure	C	Average C
1	128.1	0.864	107.6	0.853	85.9	0.836	62.6	0.835	0.847
2	76.7	0.517	64.8	0.514	51.9	0.505	37.4	0.499	0.509
3	6.9	0.047	7.9	0.063	4.6	0.045	3.5	0.047	0.051
4	-74.2	-0.500	-58.6	-0.465	-48.1	-0.468	-34.4	-0.459	-0.473
5	-9.5	-0.064	-5.1	-0.040	-5.7	-0.055	-4.1	-0.055	-0.054
6	76.5	0.516	64.8	0.514	51.9	0.505	37.4	0.499	0.509
7	15.4	0.104	15.0	0.119	13.3	0.129	11.3	0.151	0.126
8	-88.5	-0.597	-72.6	-0.576	-58.1	-0.565	-42.4	-0.565	-0.576

NOTE: Pressures are in prototype ft of water.
Piezometer locations shown on plate 49.
Figures in heading refer to control piezometer located in conduit 24 ft upstream from the test section.

$$\text{Pressure coefficient } C = \frac{\text{Pressure of numbered piezometer}}{\text{Pressure} + \frac{V^2}{2g} \text{ at control piezometer}}$$

Table 8

PRESSURE DATA - ORIGINAL GATE LIP
GATE OPEN 9.0 FT

Piez. No.	Discharge = 5862.0 cfs Pressure = 93.2 ft $V^2/2g$ = 57.9 ft Head = 151.1 ft		Discharge = 5287.0 cfs Pressure = 77.9 ft $V^2/2g$ = 47.1 ft Head = 125.0 ft		Discharge = 4756.0 cfs Pressure = 63.4 ft $V^2/2g$ = 38.1 ft Head = 101.5 ft		Discharge = 4059.0 cfs Pressure = 46.1 ft $V^2/2g$ = 27.8 ft Head = 73.9 ft		Average C
	Pressure	C	Pressure	C	Pressure	C	Pressure	C	
1	141.4	0.936	117.0	0.936	94.2	0.928	66.8	0.904	0.926
2	103.8	0.687	86.2	0.690	68.5	0.675	49.7	0.673	0.681
3	32.6	0.216	26.6	0.213	21.8	0.215	15.5	0.210	0.214
4	-72.3	-0.478	-62.4	-0.499	-49.8	-0.491	-36.0	-0.487	-0.489
5	-29.6	-0.196	-27.1	-0.217	-21.6	-0.213	-16.4	-0.222	-0.212
6	103.7	0.686	86.1	0.689	68.1	0.671	49.7	0.673	0.680
7	39.3	0.260	34.2	0.274	29.8	0.294	23.8	0.322	0.288
8	-83.7	-0.554	-70.7	-0.566	-56.0	-0.552	-40.4	-0.547	-0.555

NOTE: Pressures are in prototype ft of water.
Piezometer locations shown on plate 49.
Figures in heading refer to control piezometer located in conduit 24 ft upstream from the test section.

$$\text{Pressure coefficient } C = \frac{\text{Pressure of numbered piezometer}}{\text{Pressure} + \frac{V^2}{2g} \text{ at control piezometer}}$$

Table 9

PRESSURE DATA - MODIFIED GATE LIP
GATE OPEN 6.0 FT

Piez. No.	Discharge = 3603.0 cfs Pressure = 127.9 ft $V^2/2g$ = 21.8 ft Head = 149.7 ft		Discharge = 3278.0 cfs Pressure = 105.6 ft $V^2/2g$ = 18.1 ft Head = 123.7 ft		Discharge = 2899.0 cfs Pressure = 79.2 ft $V^2/2g$ = 14.2 ft Head = 93.4 ft		Discharge = 2500.0 cfs Pressure = 63.4 ft $V^2/2g$ = 10.5 ft Head = 73.9 ft		Average C
	Pressure	C	Pressure	C	Pressure	C	Pressure	C	
1	131.9	0.881	109.9	0.888	81.5	0.873	64.7	0.876	0.880
2	91.0	0.608	76.0	0.614	56.5	0.605	44.7	0.605	0.608
3	39.5	0.264	33.6	0.272	24.3	0.260	19.0	0.257	0.263
4	25.4	0.170	21.3	0.172	15.4	0.165	12.0	0.162	0.167
5	8.6	0.057	7.0	0.057	5.2	0.056	4.2	0.057	0.057
6	91.0	0.608	76.0	0.614	56.2	0.602	44.7	0.605	0.607
7	38.0	0.254	37.4	0.302	23.9	0.256	19.1	0.258	0.268
8	27.5	0.184	23.2	0.188	16.9	0.181	13.2	0.179	0.183

NOTE: Pressures are in prototype ft of water.
Piezometer locations shown on plate 49.
Figures in heading refer to control piezometer located in conduit 24 ft upstream from the test section.

$$\text{Pressure coefficient } C = \frac{\text{Pressure of numbered piezometer}}{\text{Pressure} + \frac{V^2}{2g} \text{ at control piezometer}}$$

Table 10

PRESSURE DATA - MODIFIED GATE LIP
GATE OPEN 9.0 FT

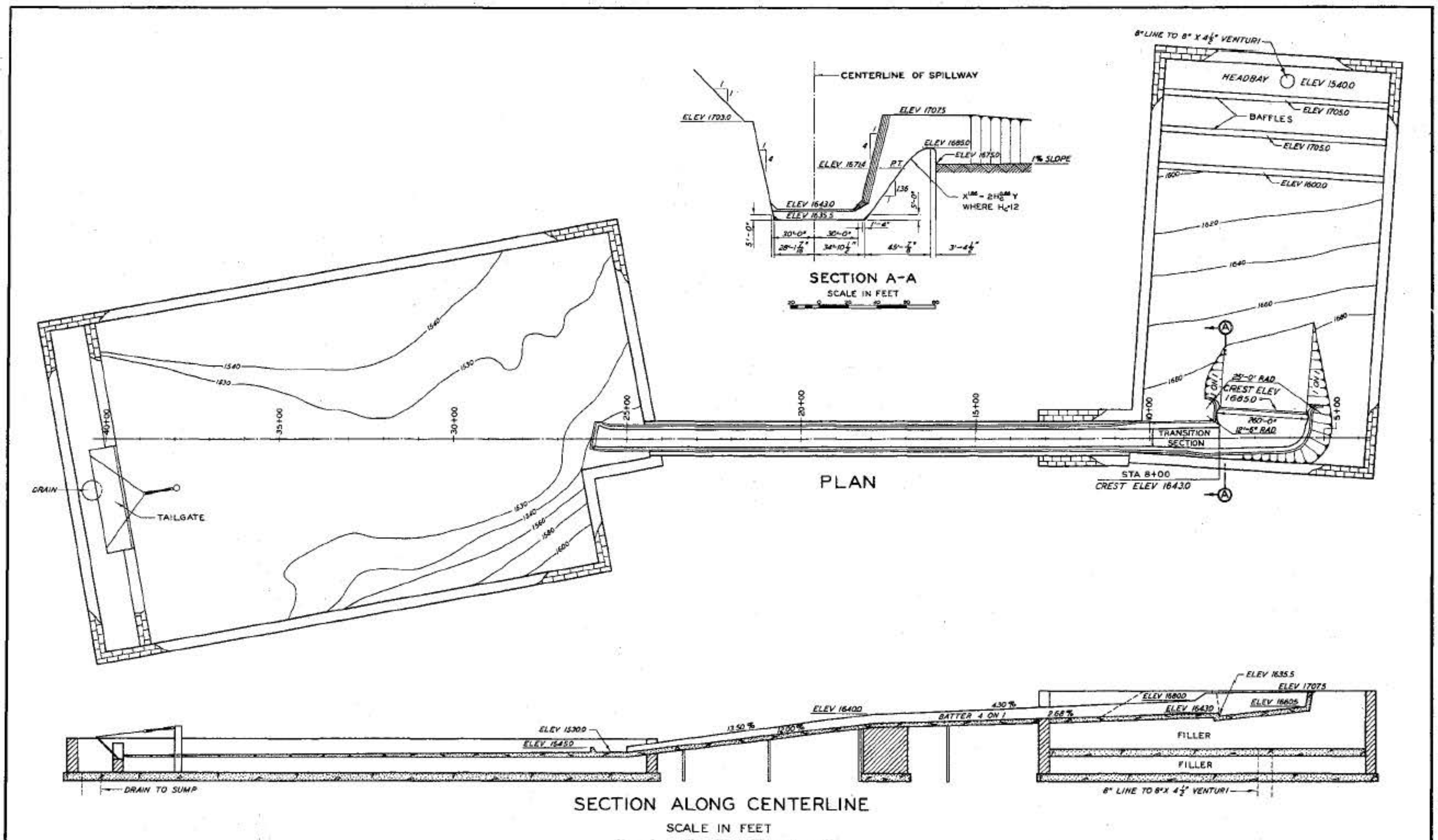
Piez. No.	Discharge = 5295.0 cfs, Pressure = 100.1 ft, $V^2/2g$ = 47.4 ft, Head = 147.5 ft: Pressure	C	Discharge = 4870.0 cfs, Pressure = 84.4 ft, $V^2/2g$ = 40.0 ft, Head = 124.4 ft: Pressure	C	Discharge = 4360.0 cfs, Pressure = 69.1 ft, $V^2/2g$ = 32.0 ft, Head = 101.1 ft: Pressure	C	Discharge = 3740.0 cfs, Pressure = 50.0 ft, $V^2/2g$ = 23.6 ft, Head = 73.6 ft: Pressure	C	Average C
1	142.7	0.967	120.7	0.970	96.6	0.955	69.2	0.940	0.958
2	118.7	0.805	100.4	0.807	79.2	0.783	57.6	0.783	0.795
3	74.0	0.502	62.7	0.504	49.4	0.489	35.5	0.482	0.494
4	44.2	0.300	37.6	0.302	29.6	0.293	20.3	0.276	0.293
5	23.6	0.160	20.1	0.162	17.0	0.168	12.2	0.166	0.164
6	118.7	0.805	100.4	0.807	79.2	0.783	57.6	0.783	0.795
7	74.0	0.502	62.6	0.503	48.7	0.482	34.5	0.469	0.489
8	42.9	0.291	36.1	0.290	29.4	0.291	20.6	0.280	0.288

NOTE: Pressures are in prototype ft of water.
Piezometer locations shown on plate 49.
Figures in heading refer to control piezometer located in conduit 24 ft upstream from the test section.

$$\text{Pressure coefficient } C = \frac{\text{Pressure of numbered piezometer}}{\text{Pressure} + \frac{V^2}{2g} \text{ at control piezometer}}$$

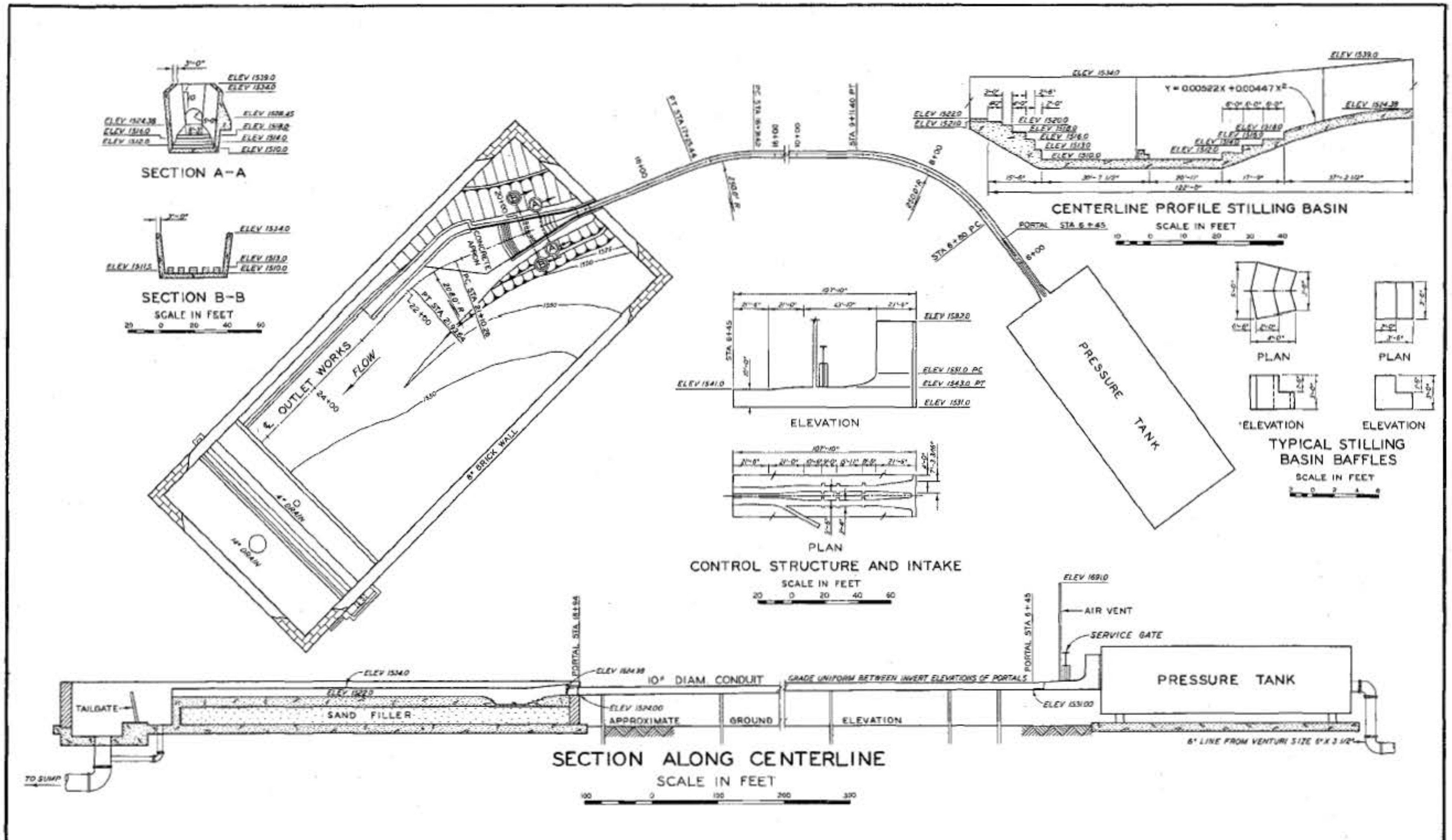
PLATES

PLATE 1

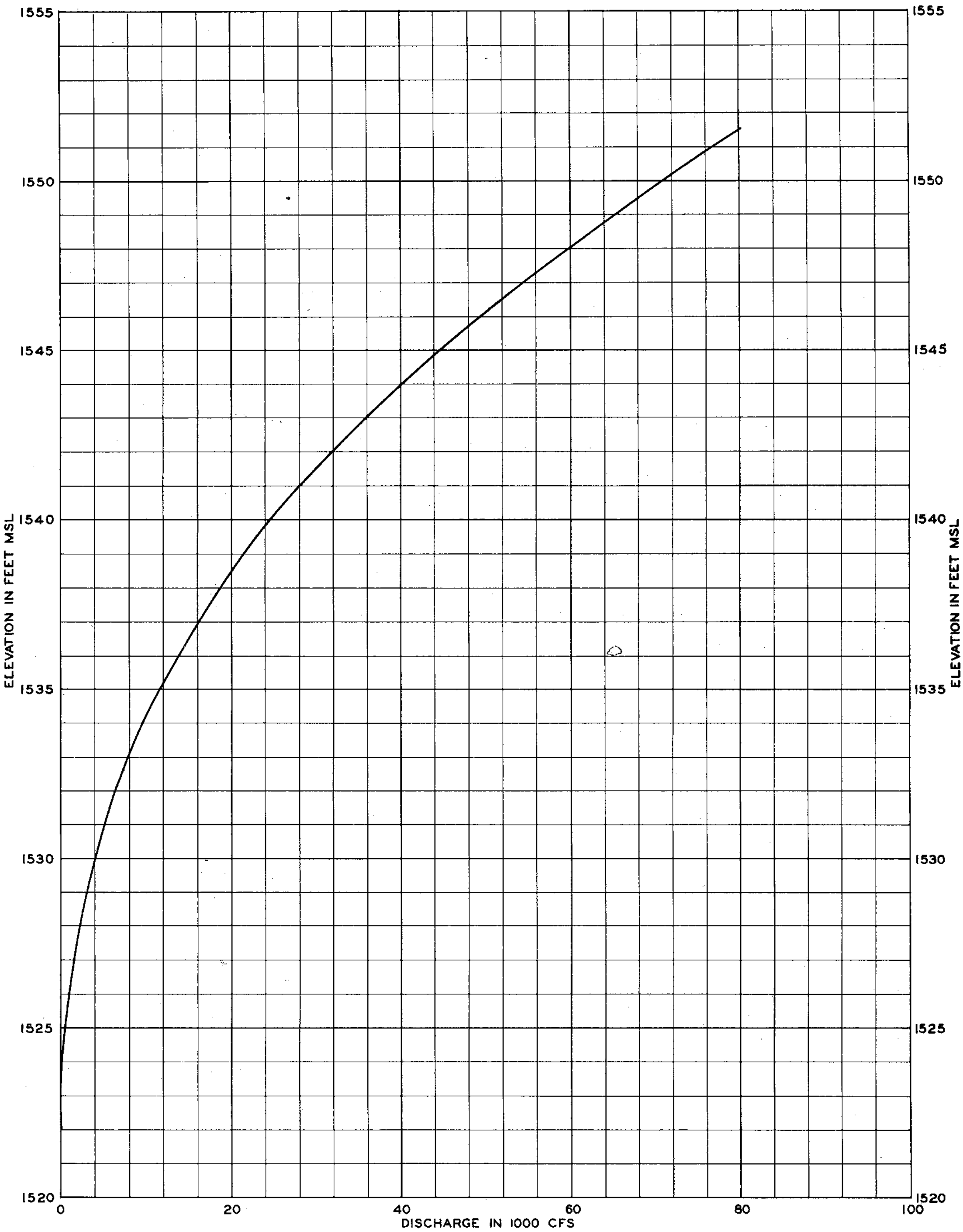


GENERAL MODEL LAYOUT
SIDE CHANNEL SPILLWAY
REVISED DESIGN

PLATE 2

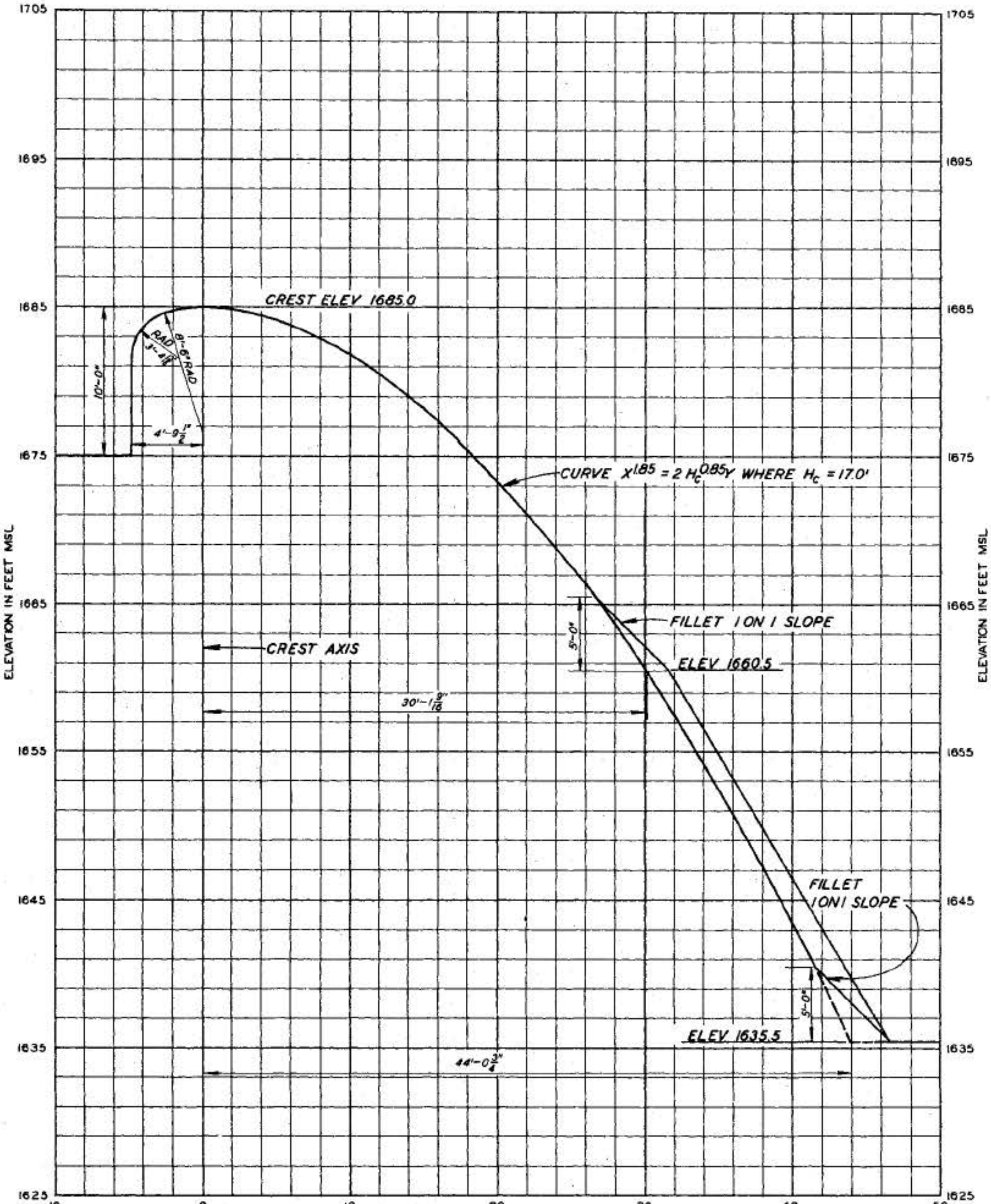


GENERAL MODEL LAYOUT
OUTLET WORKS
REVISED DESIGN



NOTE: RATING IS FOR VICINITY OF STILLING BASIN OF OUTLET WORKS 700 FT DOWNSTREAM. FROM AXIS OF DAM.

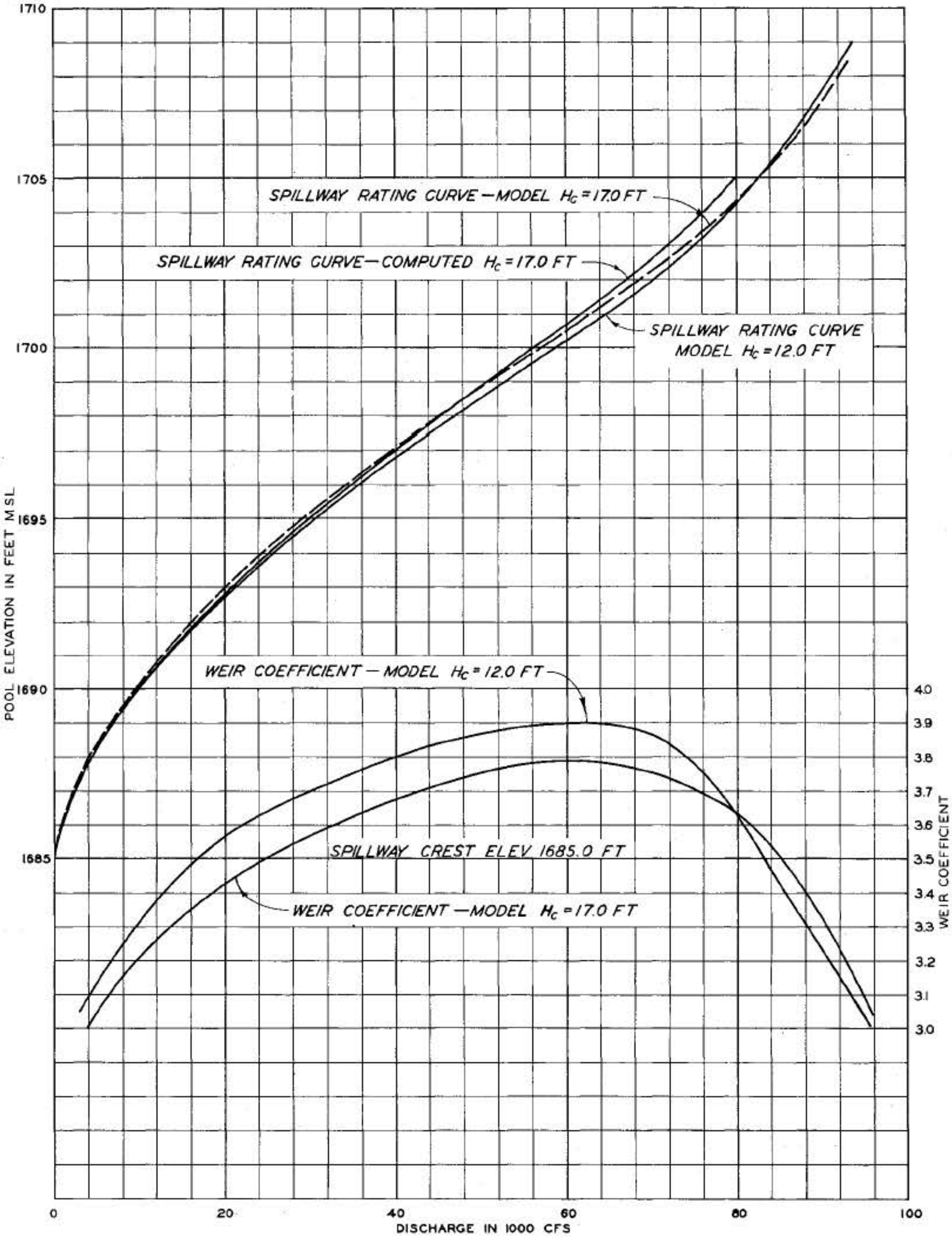
COMPUTED TAILWATER RATING CURVE



NOTE: DESIGN HEAD ON SPILLWAY CREST IS 17 FT.

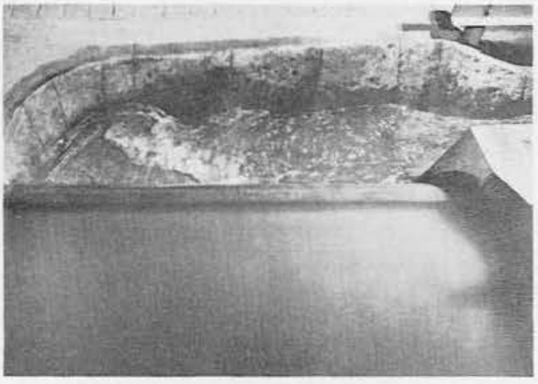
SPILLWAY WEIR
ORIGINAL DESIGN

PLATE 4

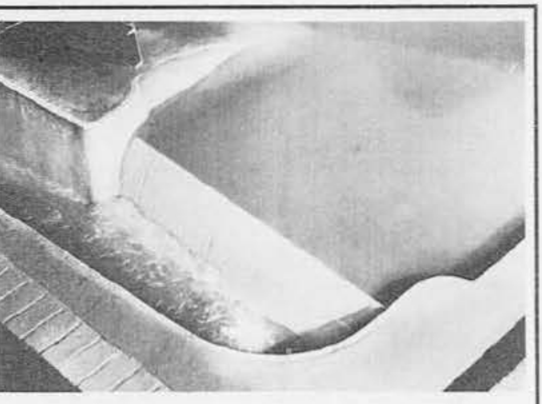


NOTE: MODEL COEFFICIENT "C" COMPUTED FROM FORMULA, $Q = CLH^{3/2}$

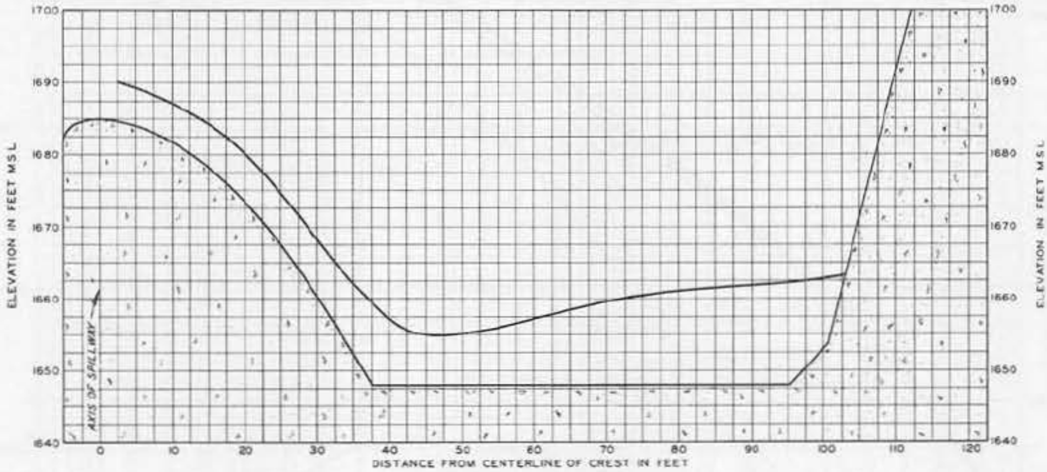
SPILLWAY RATING CURVE



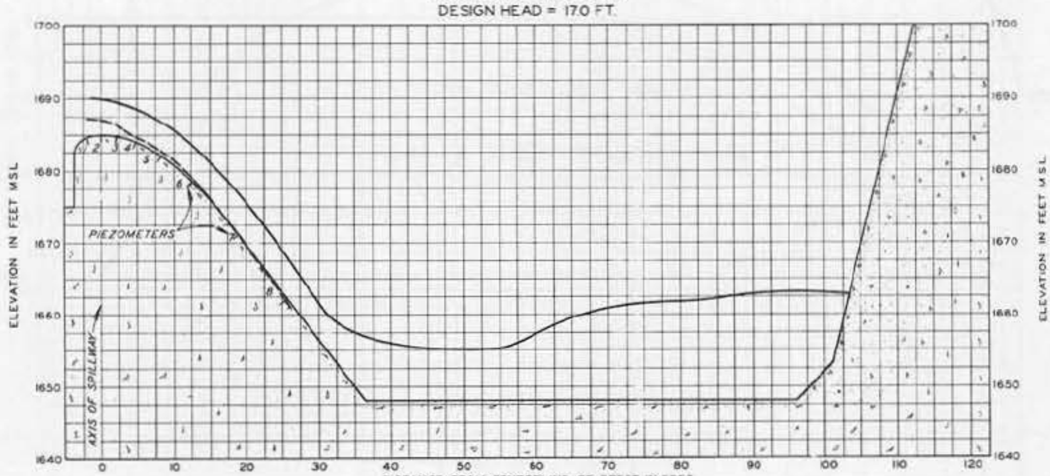
ORIGINAL DESIGN



REVISED DESIGN



ORIGINAL DESIGN
DESIGN HEAD = 17.0 FT.



REVISED DESIGN
DESIGN HEAD = 12.0 FT.

PIEZ. NO.	PIEZ. ZERO	PRESSURE
1	1684.7	2.6
2	1685.0	2.1
3	1684.6	2.0
4	1683.8	0.9
5	1682.1	0.8
6	1678.3	0.8
7	1671.1	0.0
8	1662.1	−0.5

LEGEND

——— WATER SURFACE PROFILES
– – – – PRESSURE PROFILES

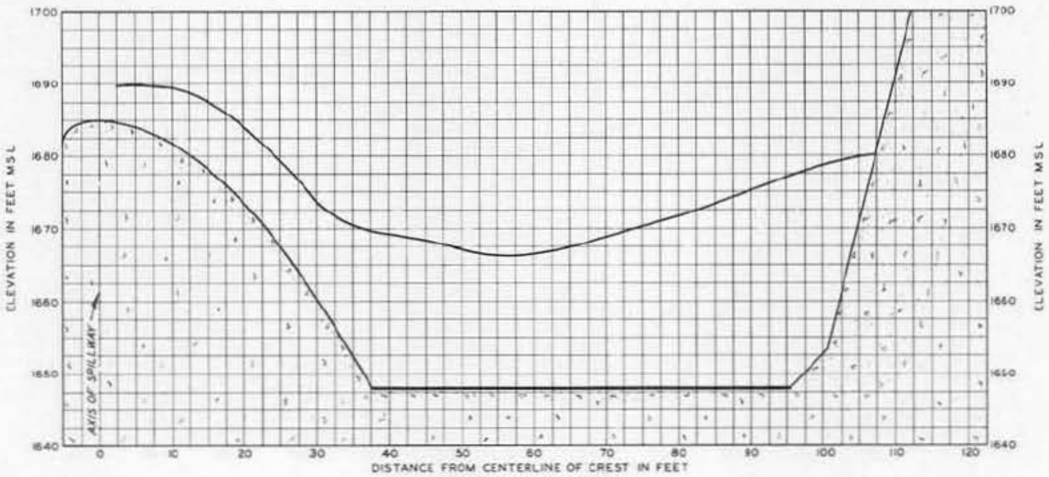
NOTE: PRESSURES ARE RECORDED IN FEET OF WATER IN PROTOTYPE.
NO PRESSURES RECORDED FOR ORIGINAL DESIGN.

WATER SURFACE AND PRESSURE PROFILES

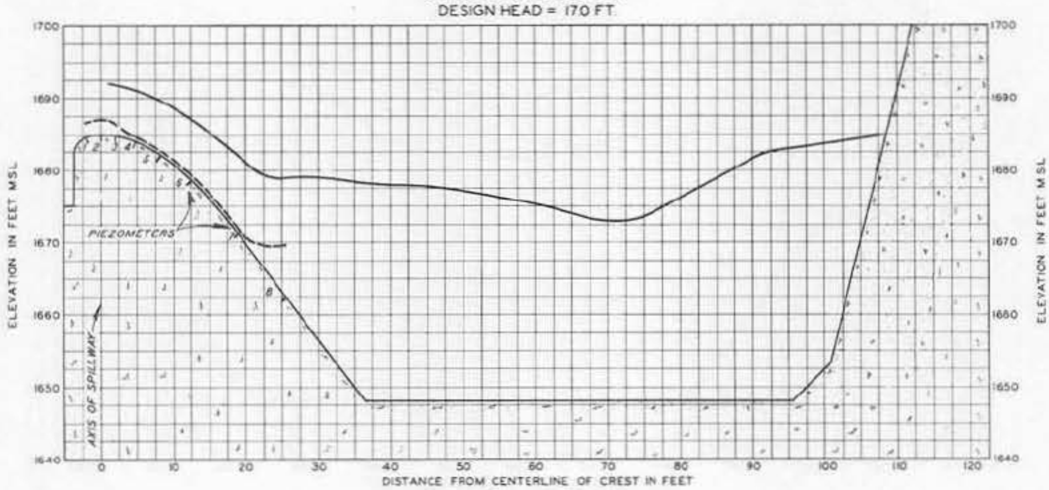
DISCHARGE 10,000 CFS
POOL ELEV 1690.0 FT

ORIGINAL DESIGN

REVISED DESIGN



ORIGINAL DESIGN
DESIGN HEAD = 17.0 FT.



REVISED DESIGN
DESIGN HEAD = 12.0 FT.

PIEZ. NO.	PIEZ. ZERO	PRESSURE
1	1684.7	1.7
2	1685.0	2.1
3	1684.6	2.0
4	1663.8	0.8
5	1682.1	0.6
6	1678.3	0.8
7	1671.1	0.3
8	1662.1	7.5

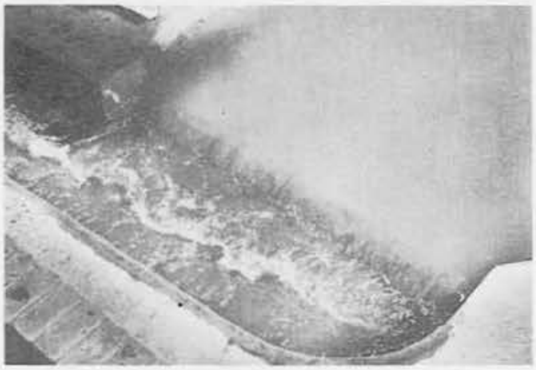
LEGEND

——— WATER SURFACE PROFILES
– – – PRESSURE PROFILES

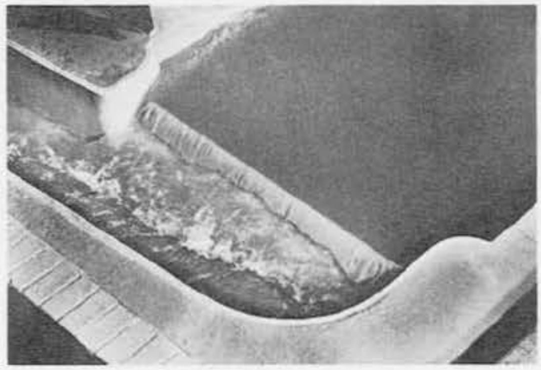
NOTE: PRESSURES ARE RECORDED IN FEET OF WATER IN PROTOTYPE.
NO PRESSURES RECORDED FOR ORIGINAL DESIGN.

WATER SURFACE AND PRESSURE PROFILES

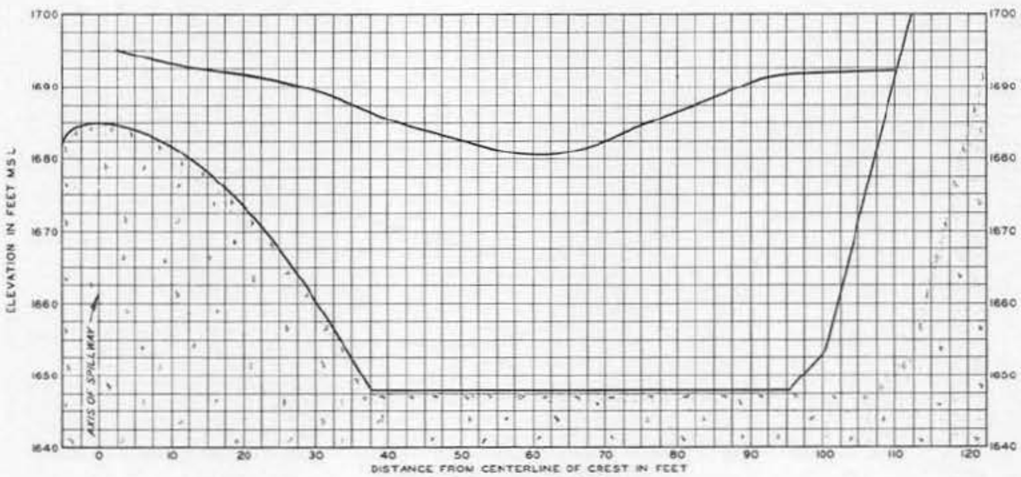
DISCHARGE 25,000 CFS
POOL ELEV 1694.22 FT



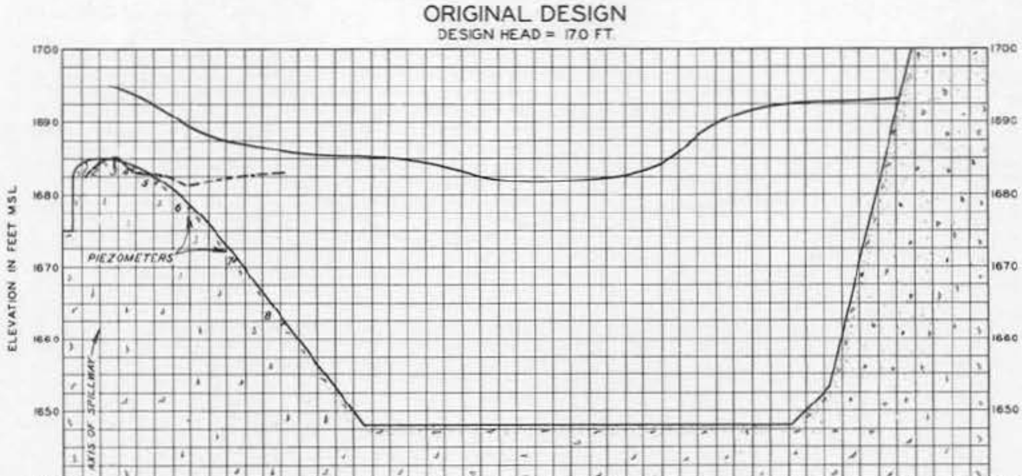
ORIGINAL DESIGN



REVISED DESIGN



ORIGINAL DESIGN
DESIGN HEAD = 17.0 FT.



REVISED DESIGN
DESIGN HEAD = 12.0 FT.

PIEZ. NO.	PIEZ. ZERO	PRESSURE
1	1684.7	-2.1
2	1685.0	-0.4
3	1684.6	0.3
4	1683.8	-0.7
5	1682.1	0.8
6	1678.3	3.3
7	1671.1	11.6
8	1662.1	22.2

LEGEND

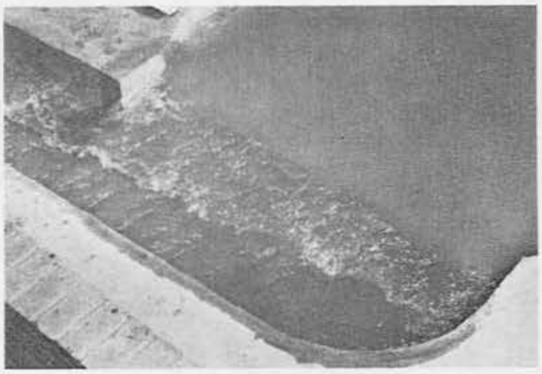
——— WATER SURFACE PROFILES
– – – PRESSURE PROFILES

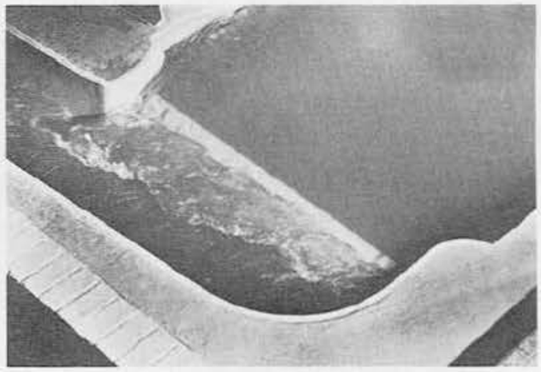
NOTE: PRESSURES ARE RECORDED IN FEET OF WATER IN PROTOTYPE.
NO PRESSURES RECORDED FOR ORIGINAL DESIGN.

WATER SURFACE AND PRESSURE PROFILES

DISCHARGE 50,000 CFS
POOL ELEV 1698.75 FT

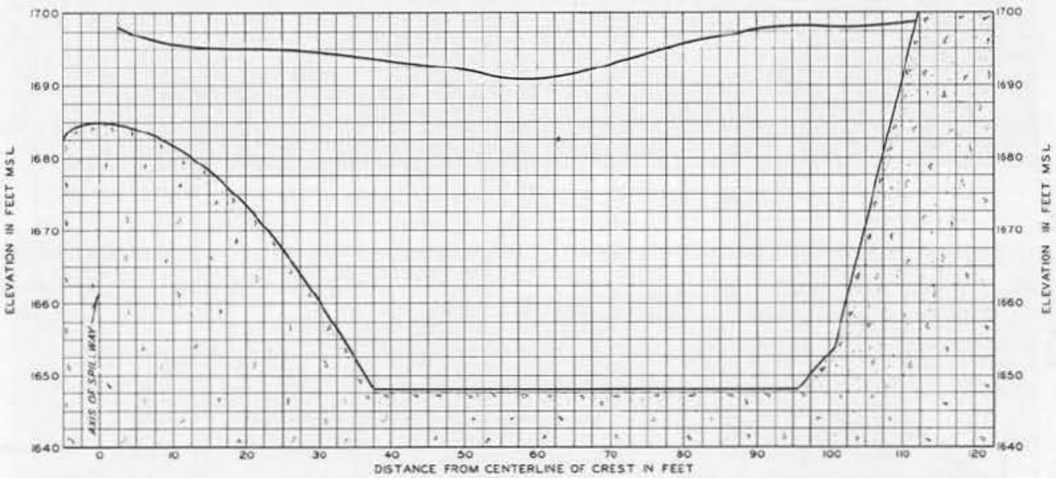
PLATE 8





ORIGINAL DESIGN

REVISED DESIGN



ORIGINAL DESIGN
DESIGN HEAD = 170 FT.

REVISED DESIGN
DESIGN HEAD = 120 FT.

PIEZ. NO.	PIEZ. ZERO	PRESSURE
1	16847	-5.2
2	16850	-1.4
3	16846	-1.1
4	16838	06
5	1682.1	4.5
6	1678.3	108
7	1671.1	222
8	1662.1	31.8

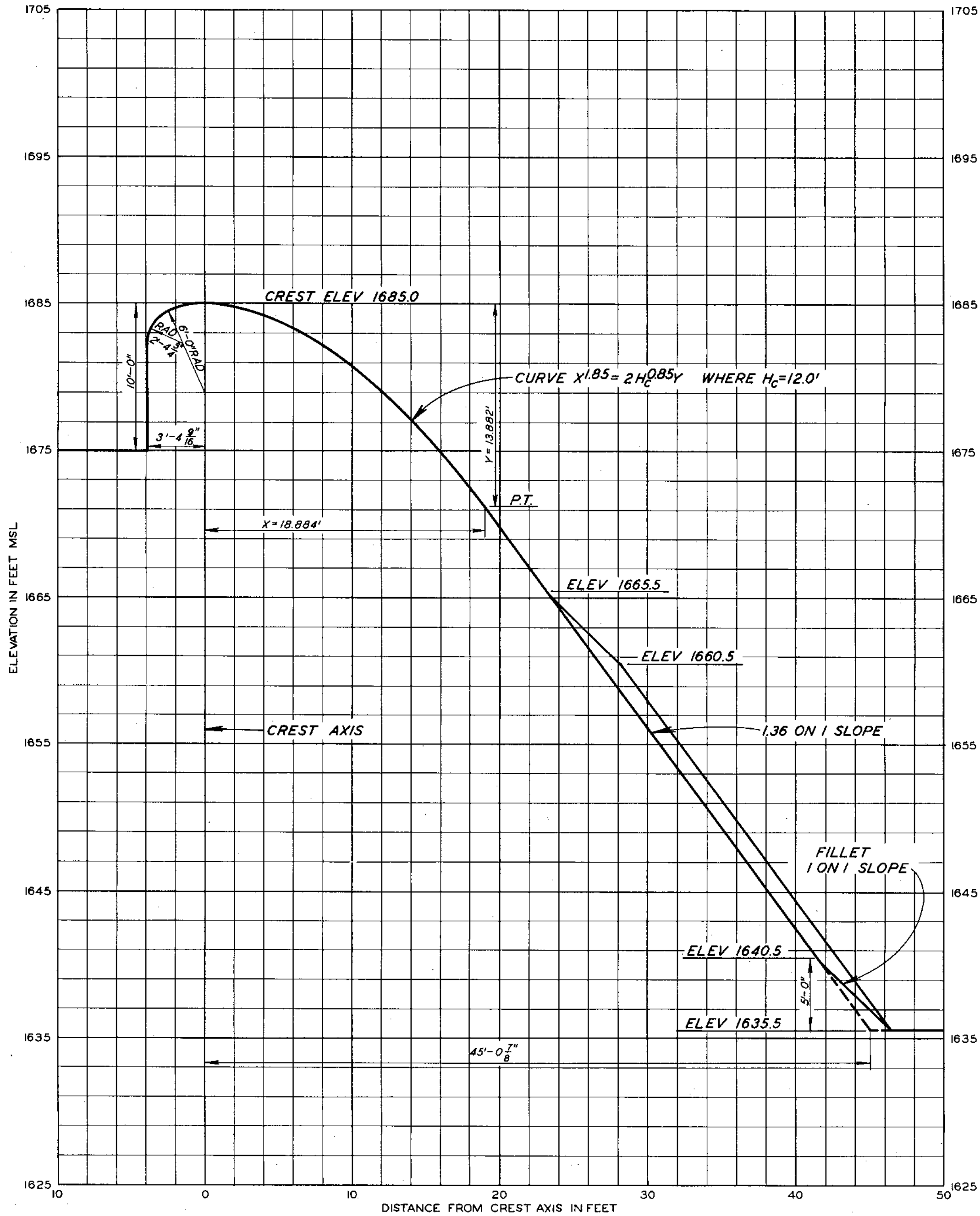
LEGEND

——— WATER SURFACE PROFILES
- - - - PRESSURE PROFILES

NOTE: PRESSURES ARE RECORDED IN FEET OF WATER IN PROTOTYPE.
NO PRESSURES RECORDED FOR ORIGINAL DESIGN.

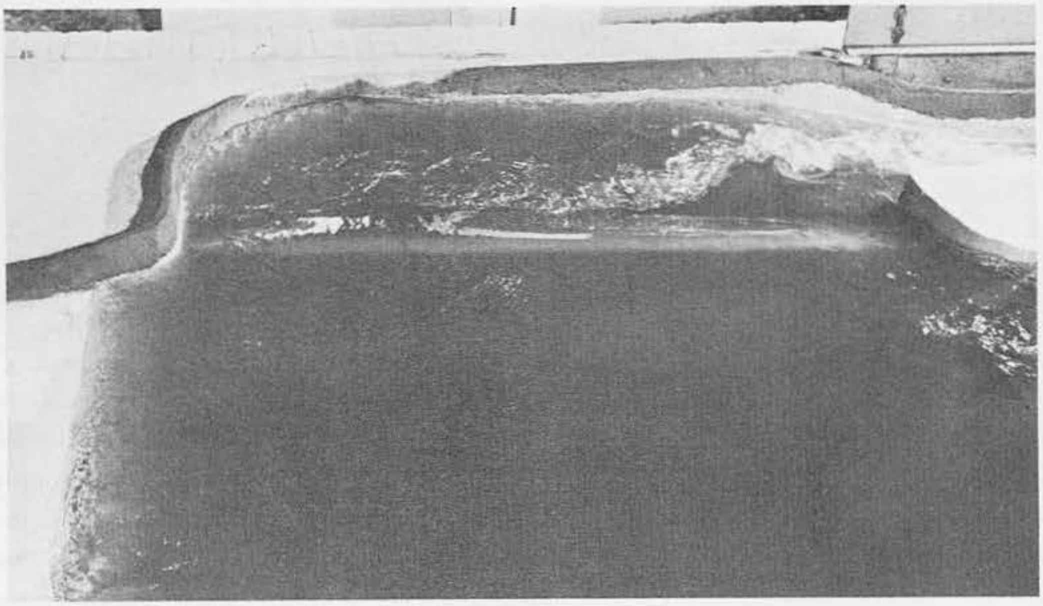
WATER SURFACE AND PRESSURE PROFILES

DISCHARGE 70,000 CFS
POOL ELEV 1702.20 FT

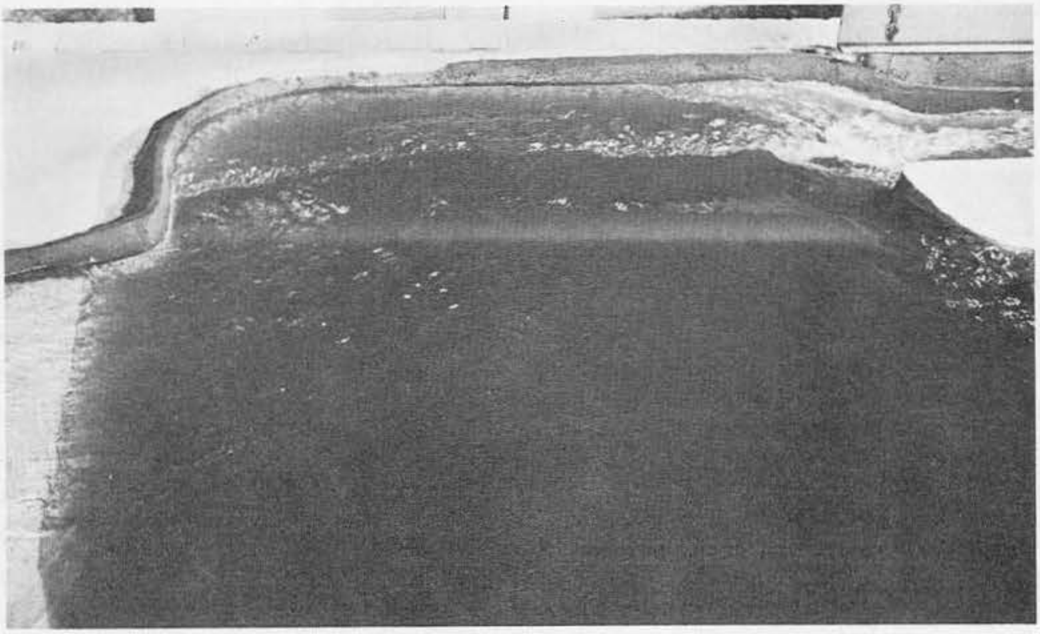


NOTE: DESIGN HEAD ON SPILLWAY CREST IS 12 FT.

SPILLWAY WEIR
REVISED DESIGN



HEAD = 20.1 FT DISCHARGE = 82,320 CFS

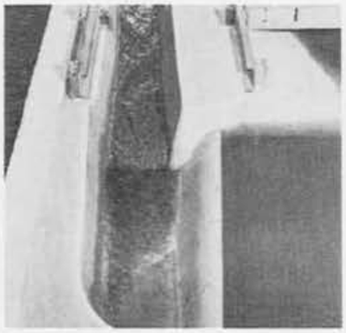


HEAD = 24.4 FT DISCHARGE = 93,500 CFS

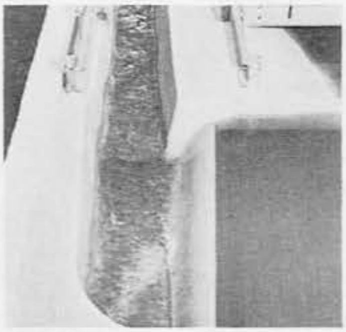
PIEZ. NO.	PIEZ. ZERO	Q = 82,320 CFS POOL ELEV. = 1705.1	Q = 93,500 CFS POOL ELEV. = 1709.4
		PRESSURE IN FT. - PROTOTYPE	
1	1684.7	-0.6	8.7
2	1685.0	6.4	14.1
3	1684.6	8.3	17.0
4	1683.8	12.3	20.3
5	1682.1	15.0	22.0
6	1678.3	20.0	25.8
7	1671.1	26.3	32.5
8	1662.1	34.0	40.0

NOTE: LOCATION OF PIEZOMETERS ARE AS SHOWN ON PRESSURE PROFILES, DESIGN HEAD FOR WEIR IS 12.0 FT.

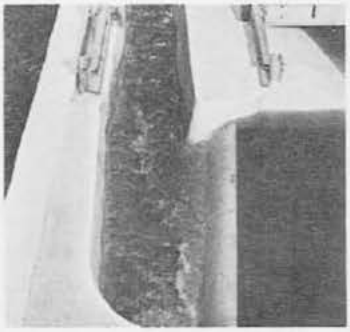
SIDE CHANNEL SPILLWAY WEIR
REVISED DESIGN
SUBMERGENCE EFFECTS



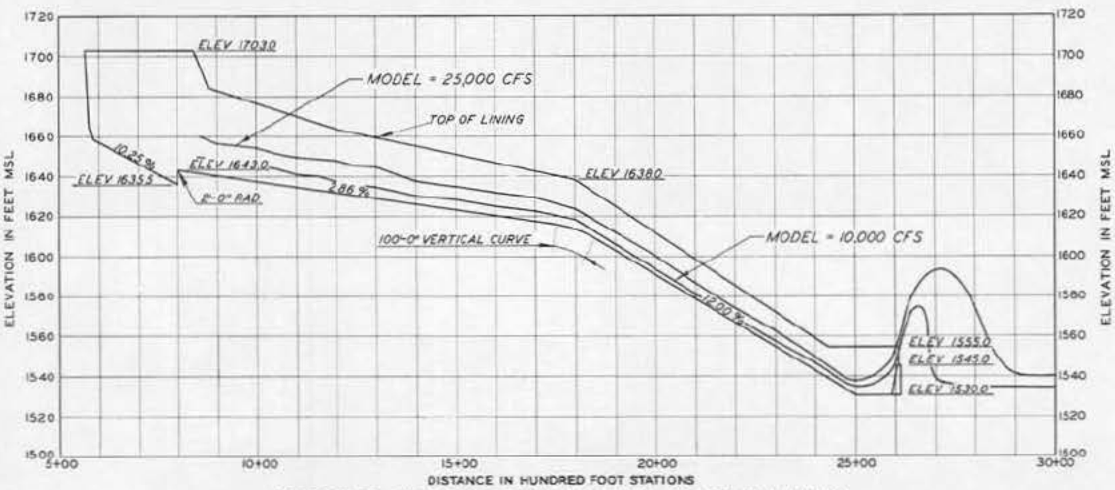
DISCHARGE = 5,000 CFS



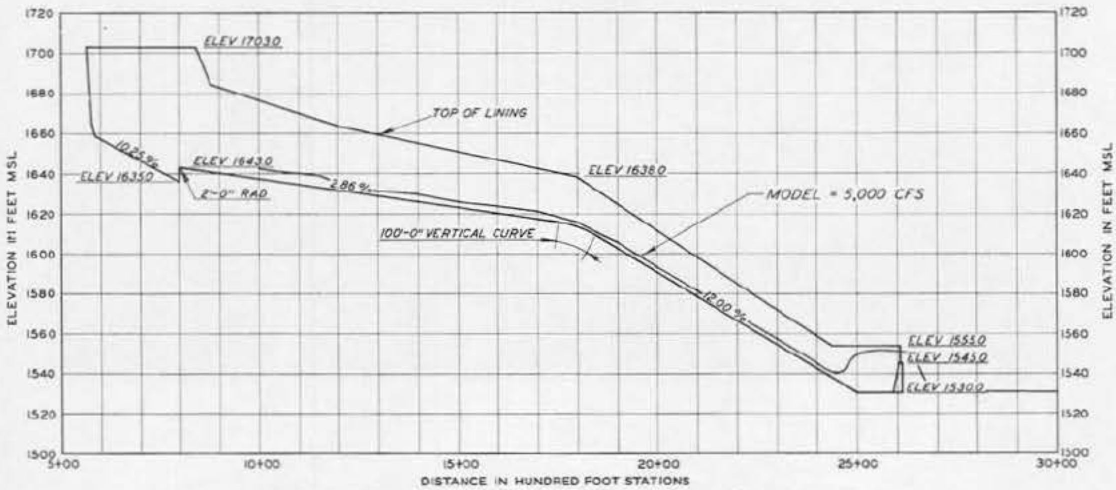
DISCHARGE = 10,000 CFS



DISCHARGE = 25,000 CFS



PROFILE ALONG CENTERLINE OF SPILLWAY



PROFILE ALONG CENTERLINE OF SPILLWAY

NOTE: TYPE D-1 DISPERSAL BUCKET IN MODEL.

TEST CONDITIONS		
DISCHARGE	POOL ELEV	TAILWATER ELEV
5000	1688.35	1531.0
10,000	1690.00	1534.2
25,000	1694.25	1540.2
50,000	1698.75	1546.2
70,000	1702.00	1549.8

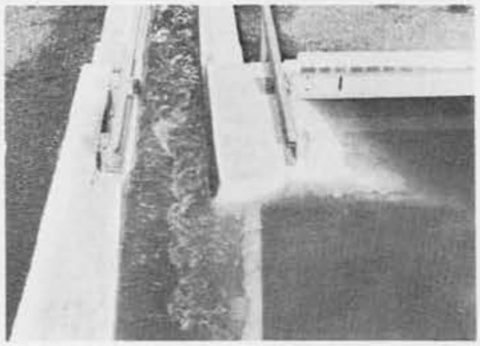
WATER SURFACE PROFILES

SIDE CHANNEL SPILLWAY

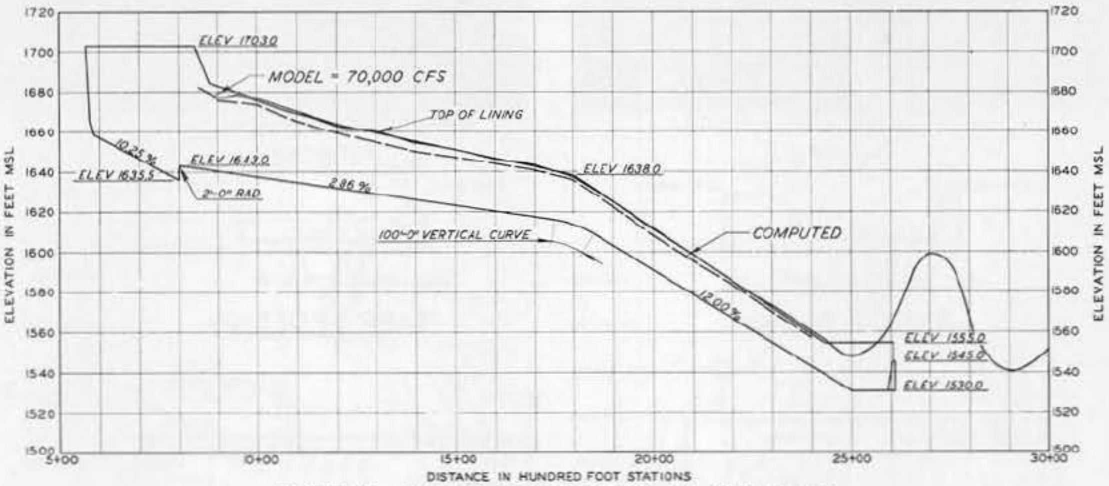
FINAL DESIGN

DISCHARGES 5000, 10,000 AND 25,000 CFS

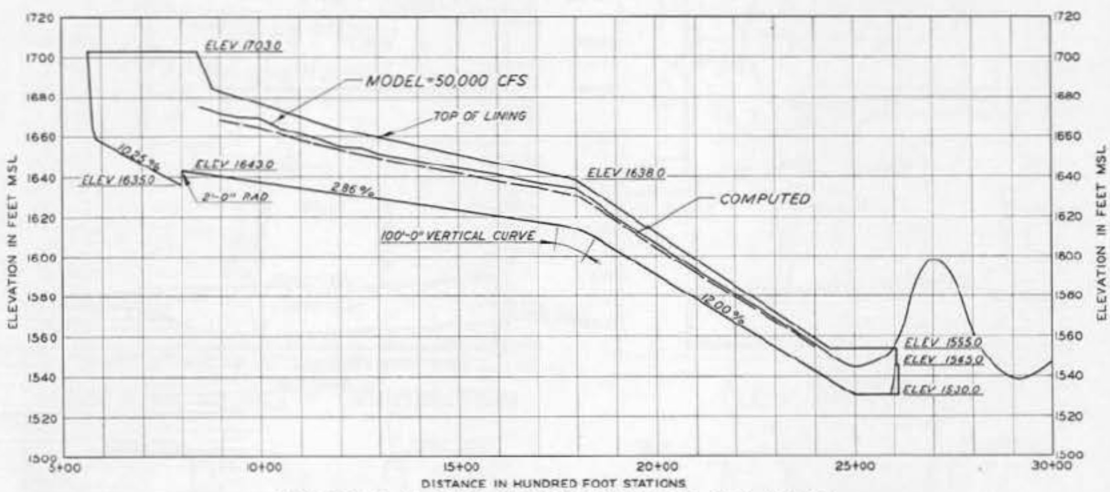
DISCHARGE = 50,000 CFS



DISCHARGE = 70,000 CFS



PROFILE ALONG CENTERLINE OF SPILLWAY



PROFILE ALONG CENTERLINE OF SPILLWAY

NOTE: TYPE D-1 DISPERSAL BUCKET IN MODEL

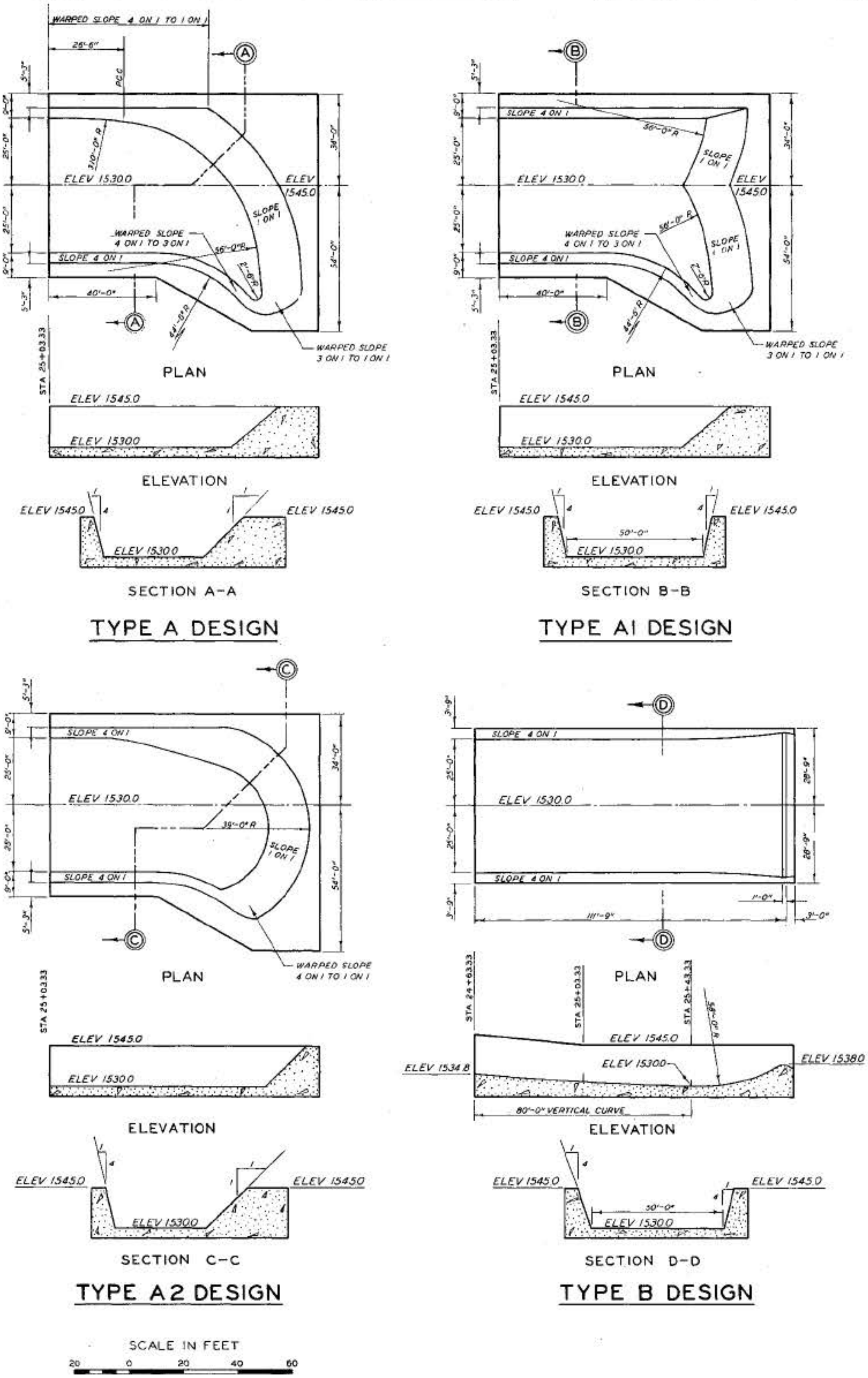
TEST CONDITIONS		
DISCHARGE	POOL ELEV	TAILWATER ELEV
5000	1688.35	1531.0
10,000	1690.00	1534.2
25,000	1694.25	1540.2
50,000	1698.75	1546.2
70,000	1702.00	1549.6

WATER SURFACE PROFILES

SIDE CHANNEL SPILLWAY

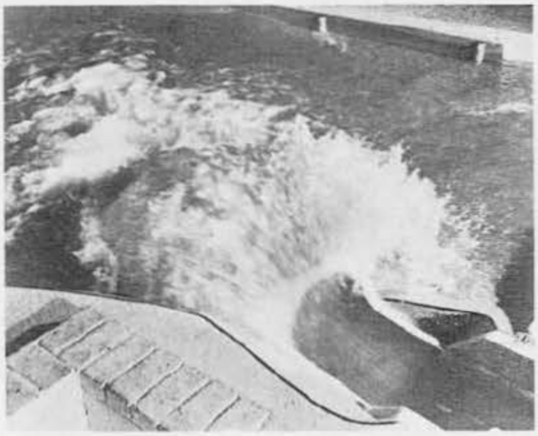
FINAL DESIGN

DISCHARGES 50,000 AND 70,000 CFS

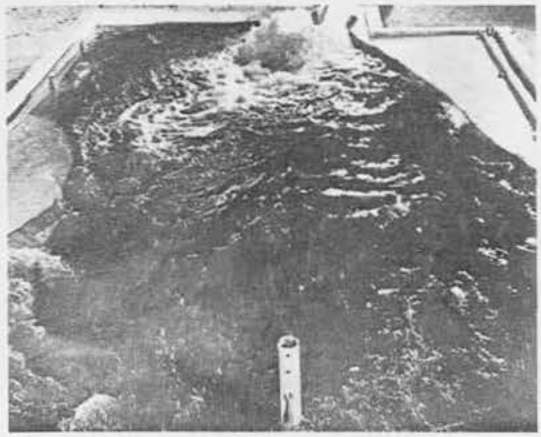


DISPERSAL BUCKETS

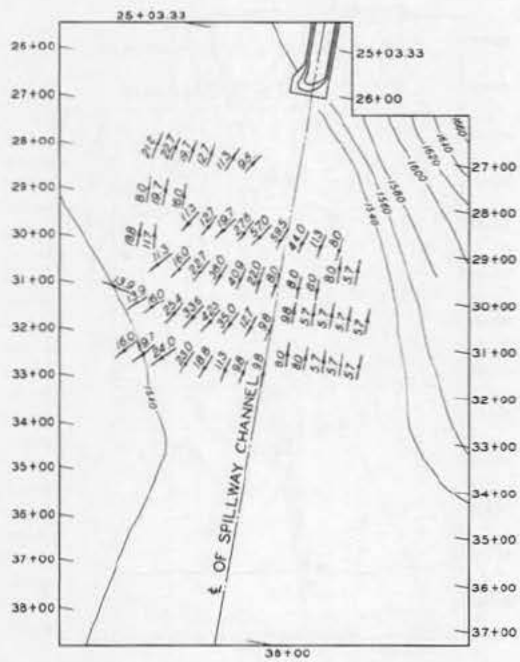
TYPES A, A1, A2, AND B DESIGNS



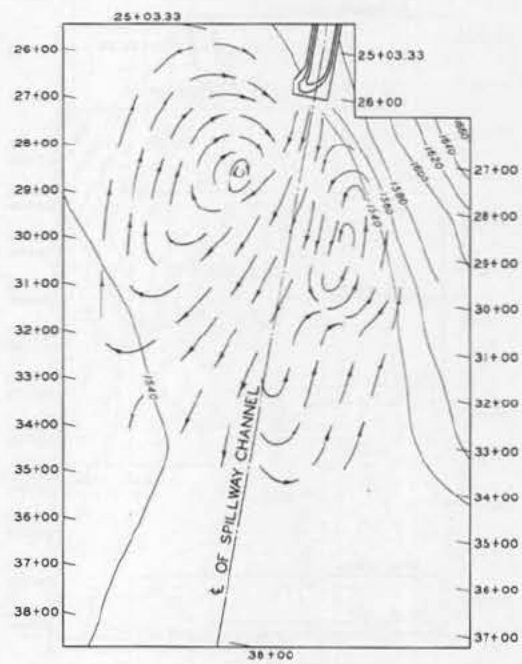
DISPERSAL BUCKET



EXIT AREA



BOTTOM VELOCITY DISTRIBUTION



FLOW PATTERN

NOTE: STATIONS REFER TO DISTANCE ALONG CENTERLINE OF SPILLWAY CHANNEL.

TEST CONDITIONS

DISCHARGE	70,000 C.F.S.
TAILWATER ELEVATION	1549.8 FT

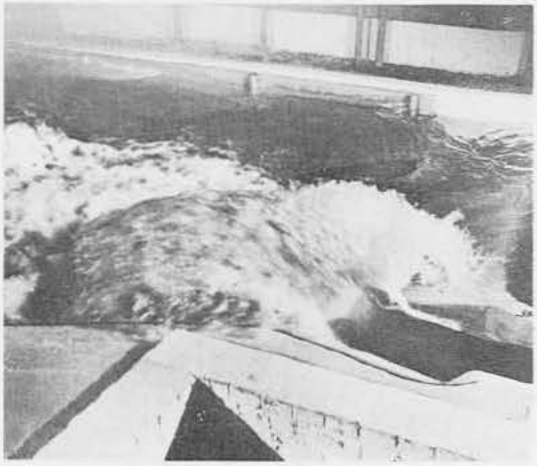
FLOW CHARACTERISTICS

TYPE A DISPERSAL BUCKET

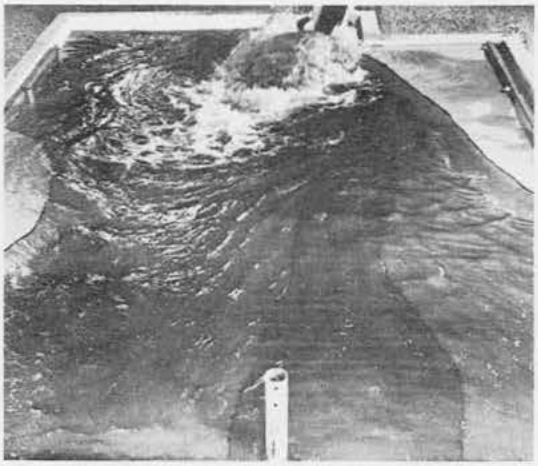
DISCHARGE = 70,000 CFS

SCALE IN FEET

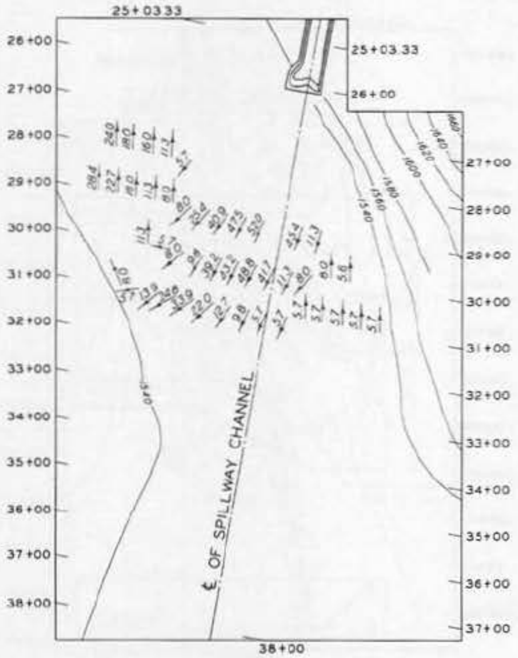
100 0 100 200 300 400 500



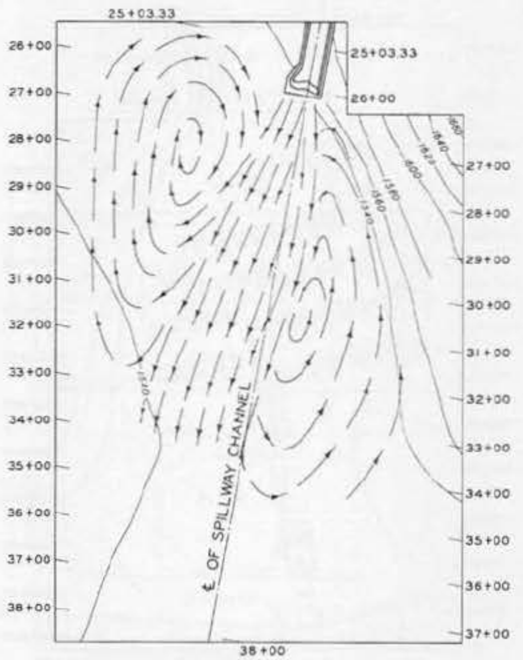
DISPERSAL BUCKET



EXIT AREA



BOTTOM VELOCITY DISTRIBUTION



FLOW PATTERN

NOTE: STATIONS REFER TO DISTANCE ALONG CENTERLINE OF SPILLWAY CHANNEL.

TEST CONDITIONS

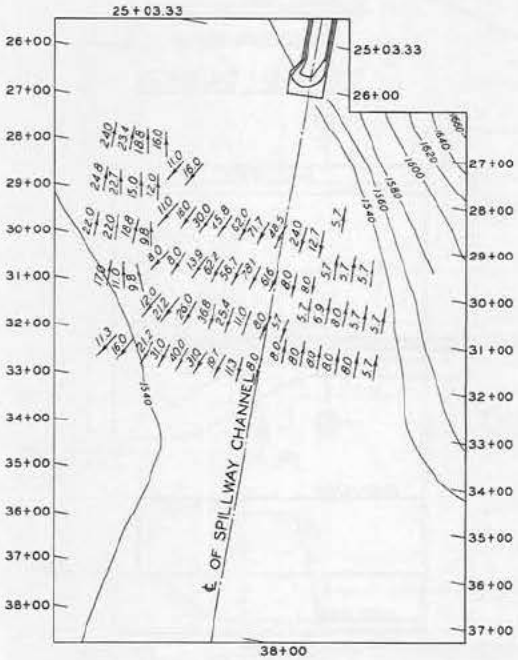
DISCHARGE	70,000 C.F.S.
TAILWATER ELEVATION	1549.8 FT

FLOW CHARACTERISTICS
TYPE A1 DISPERSAL BUCKET
DISCHARGE = 70,000 CFS

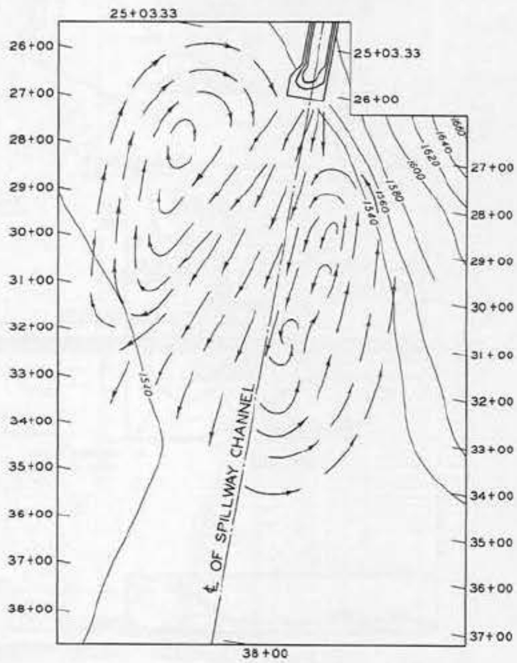
SCALE IN FEET

100 0 100 200 300 400 500

EXIT AREA



BOTTOM VELOCITY DISTRIBUTION



FLOW PATTERN

NOTE: STATIONS REFER TO DISTANCE ALONG CENTERLINE OF SPILLWAY CHANNEL.

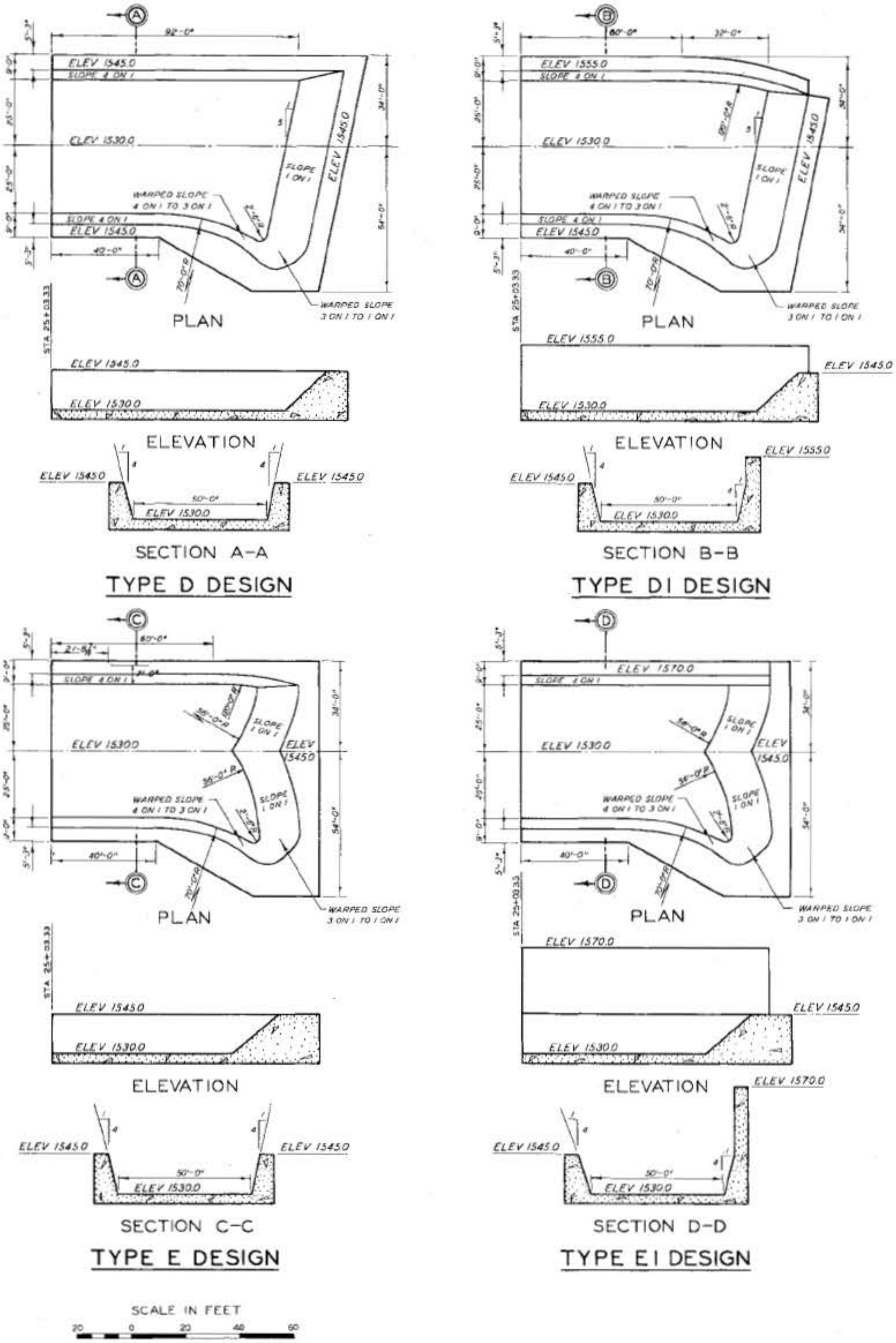
TEST CONDITIONS

DISCHARGE	70,000 C.F.S.
TAILWATER ELEVATION	1549.8 FT

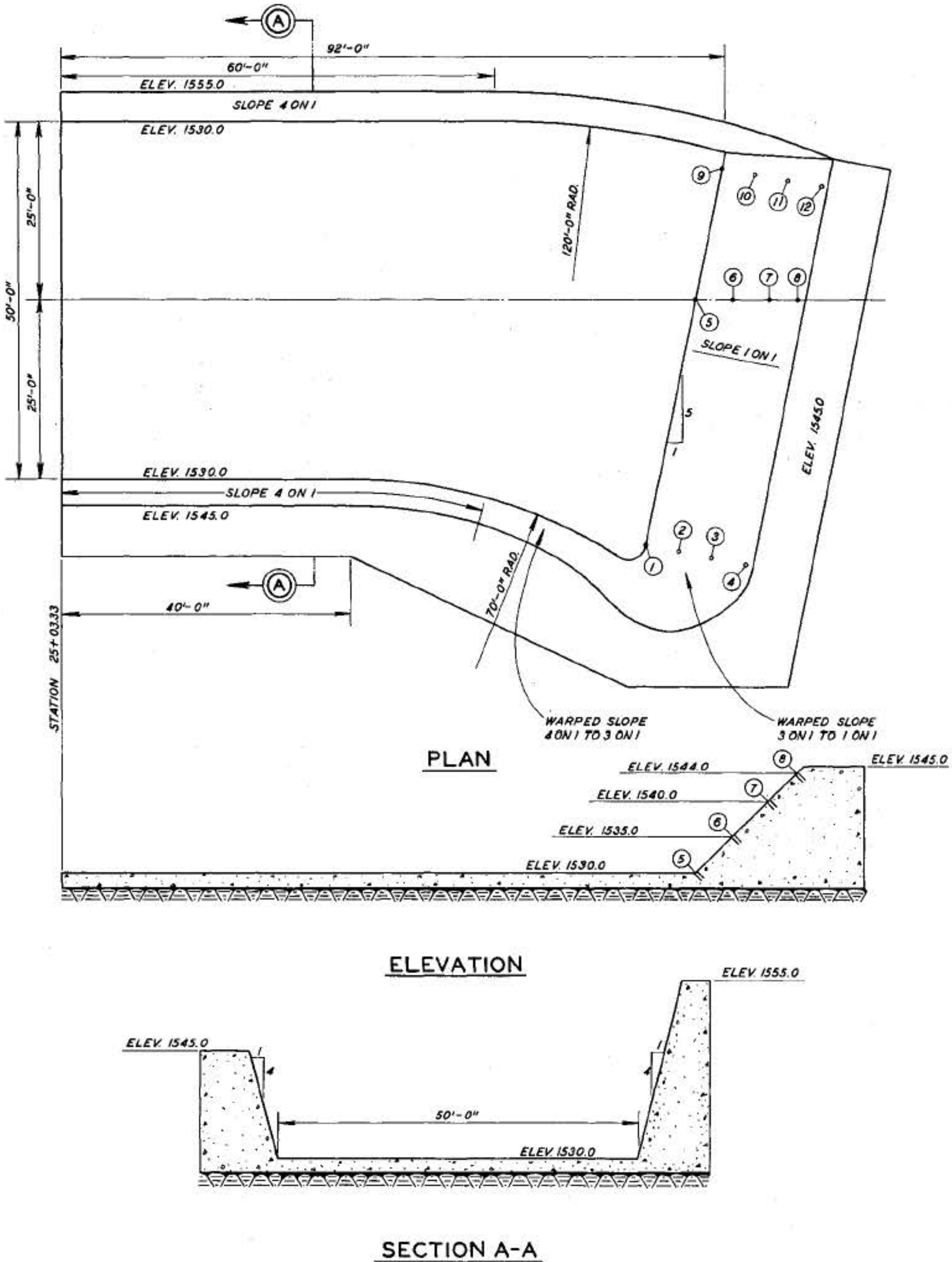
FLOW CHARACTERISTICS
TYPE A2 DISPERSAL BUCKET
DISCHARGE = 70,000 CFS

SCALE IN FEET

100 0 100 200 300 400 500



DISPERSAL BUCKETS
TYPES D, DI, E AND EI DESIGNS



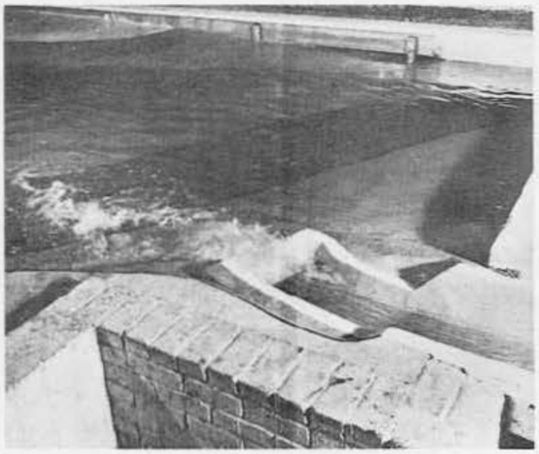
NOTE: ALL DIMENSIONS ARE IN PROTOTYPE UNITS.

PIEZOMETER LOCATIONS SHOWN THUS (12)

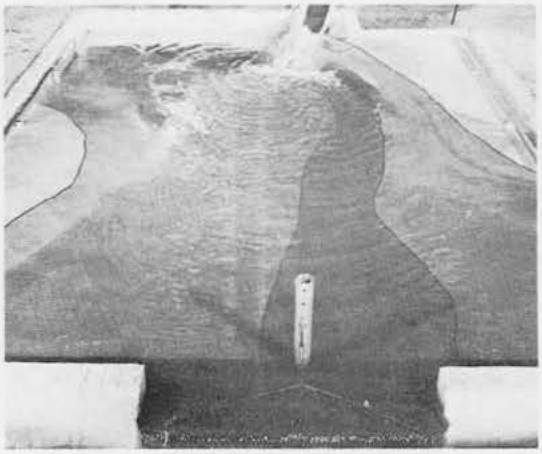
SCALE

PROTOTYPE 25 0 25FT

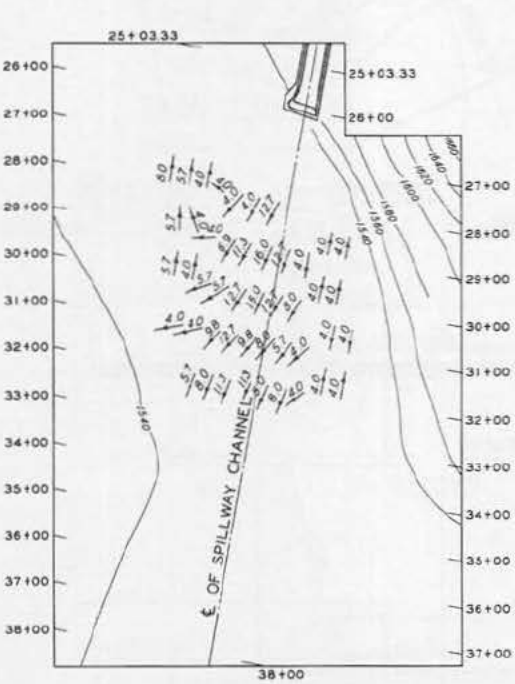
PIEZOMETER LOCATIONS
DISPERSAL BUCKET
TYPE DI DESIGN



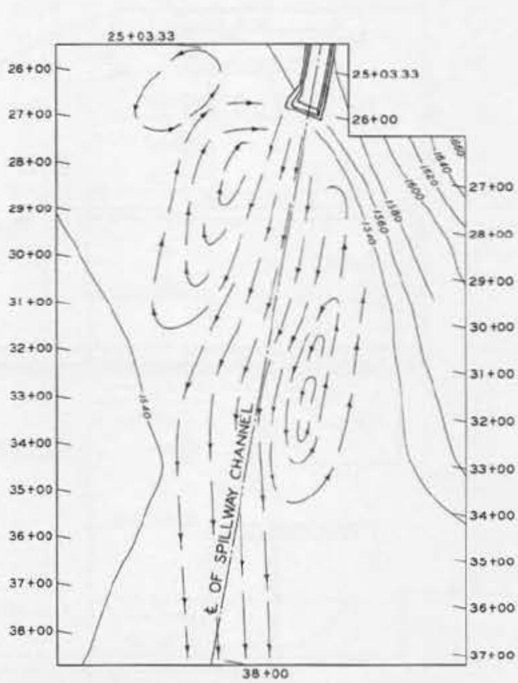
DISPERSAL BUCKET



EXIT AREA



BOTTOM VELOCITY DISTRIBUTION



FLOW PATTERN

NOTE: STATIONS REFER TO DISTANCE ALONG CENTERLINE OF SPILLWAY CHANNEL.

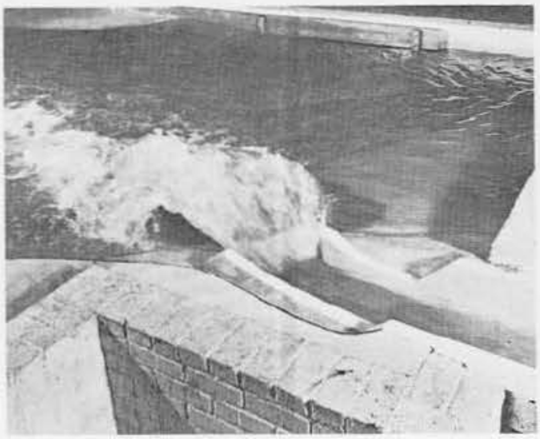
TEST CONDITIONS

DISCHARGE	10,000 C.F.S.
TAILWATER ELEVATION	1534.2 FT

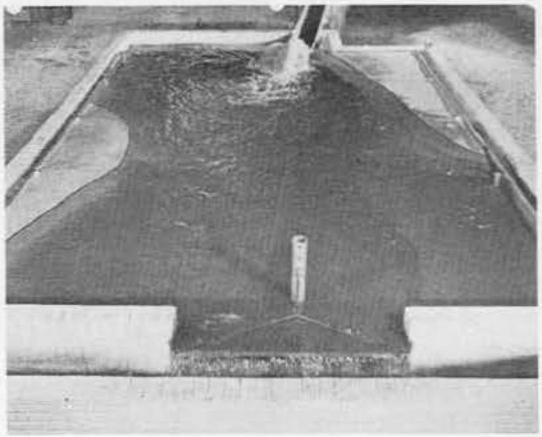
FLOW CHARACTERISTICS
TYPE DI DISPERSAL BUCKET
DISCHARGE = 10,000 CFS

SCALE IN FEET

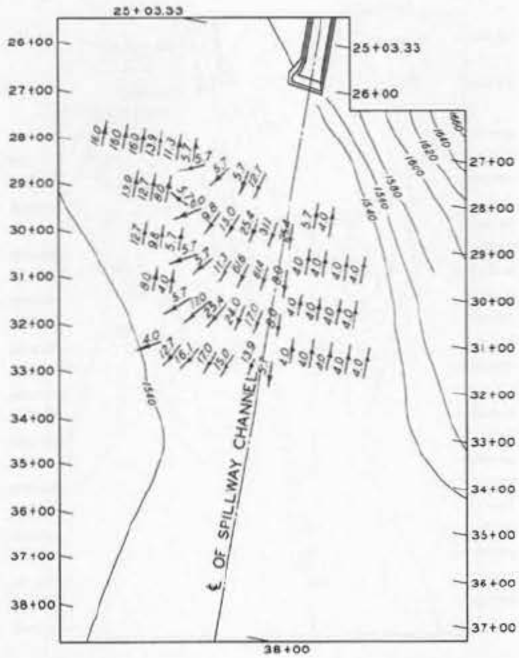
100 0 100 200 300 400 500



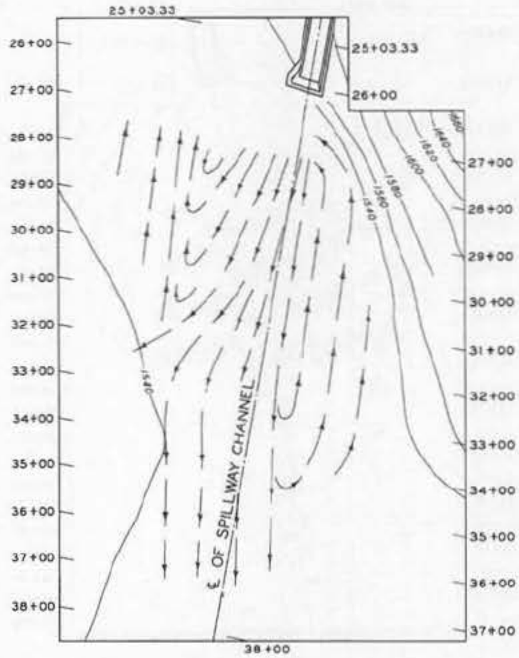
DISPERSAL BUCKET



EXIT AREA



BOTTOM VELOCITY DISTRIBUTION



FLOW PATTERN

NOTE: STATIONS REFER TO DISTANCE ALONG CENTERLINE OF SPILLWAY CHANNEL.

TEST CONDITIONS

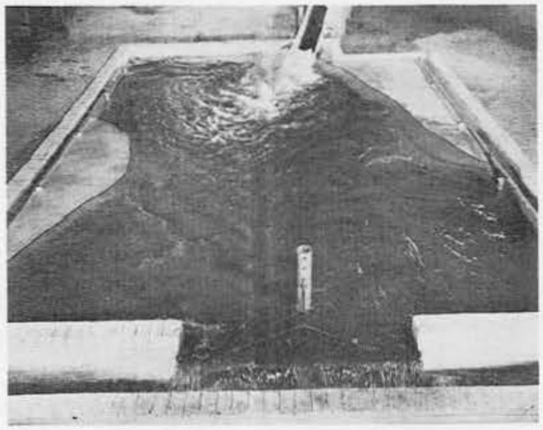
DISCHARGE	25,000 C.F.S.
TAILWATER ELEVATION	1540.2 FT

FLOW CHARACTERISTICS
TYPE D1 DISPERSAL BUCKET
DISCHARGE = 25,000 CFS

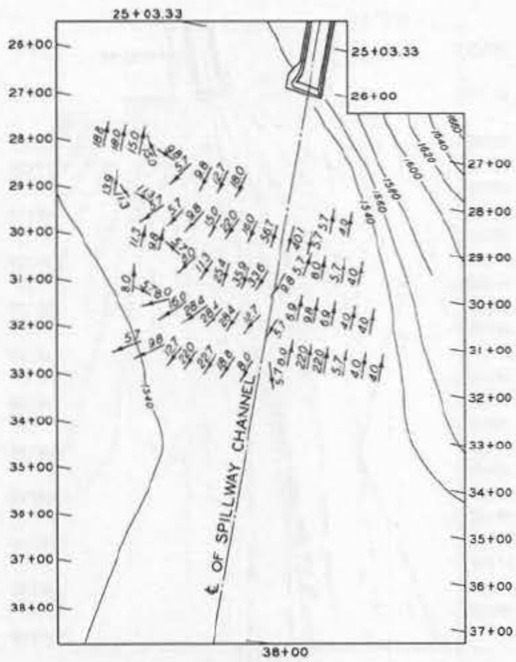
SCALE IN FEET

100 0 100 200 300 400 500

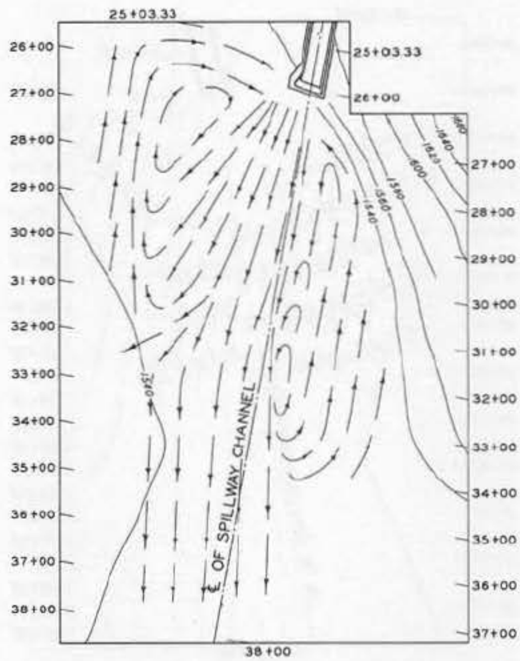
DISPERSAL BUCKET



EXIT AREA



BOTTOM VELOCITY DISTRIBUTION



FLOW PATTERN

NOTE: STATIONS REFER TO DISTANCE ALONG CENTERLINE OF SPILLWAY CHANNEL.

TEST CONDITIONS

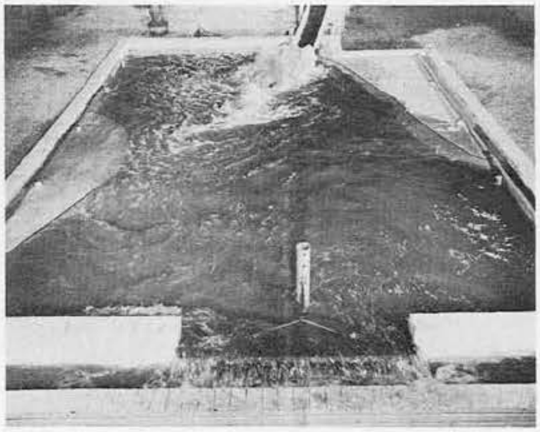
DISCHARGE	50,000 C.F.S.
TAILWATER ELEVATION	1546.2 FT

FLOW CHARACTERISTICS
TYPE D1 DISPERSAL BUCKET
DISCHARGE = 50,000 CFS

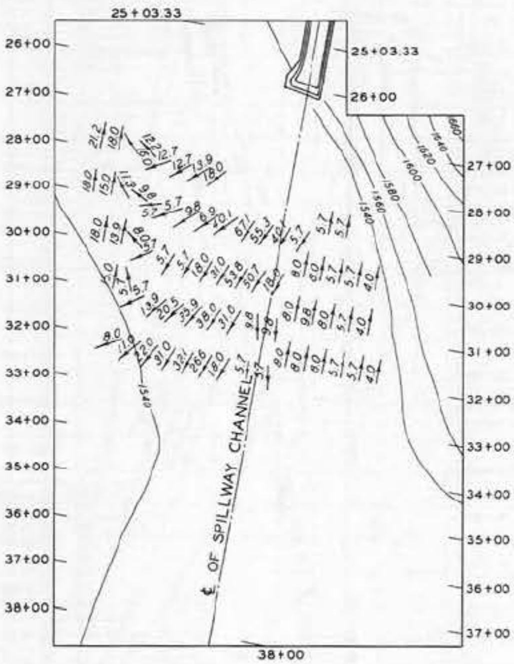
SCALE IN FEET

100 0 100 200 300 400 500

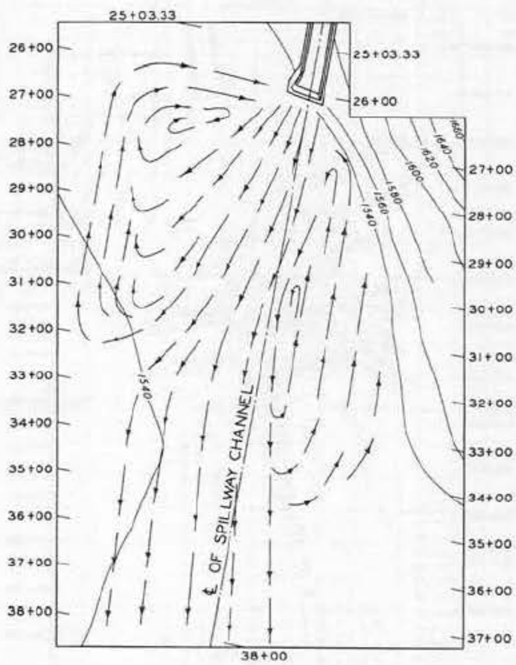
DISPERSAL BUCKET



EXIT AREA



BOTTOM VELOCITY DISTRIBUTION



FLOW PATTERN

NOTE: STATIONS REFER TO DISTANCE ALONG CENTERLINE OF SPILLWAY CHANNEL.

TEST CONDITIONS

DISCHARGE	70,000 C.F.S.
TAILWATER ELEVATION	1549.8 FT

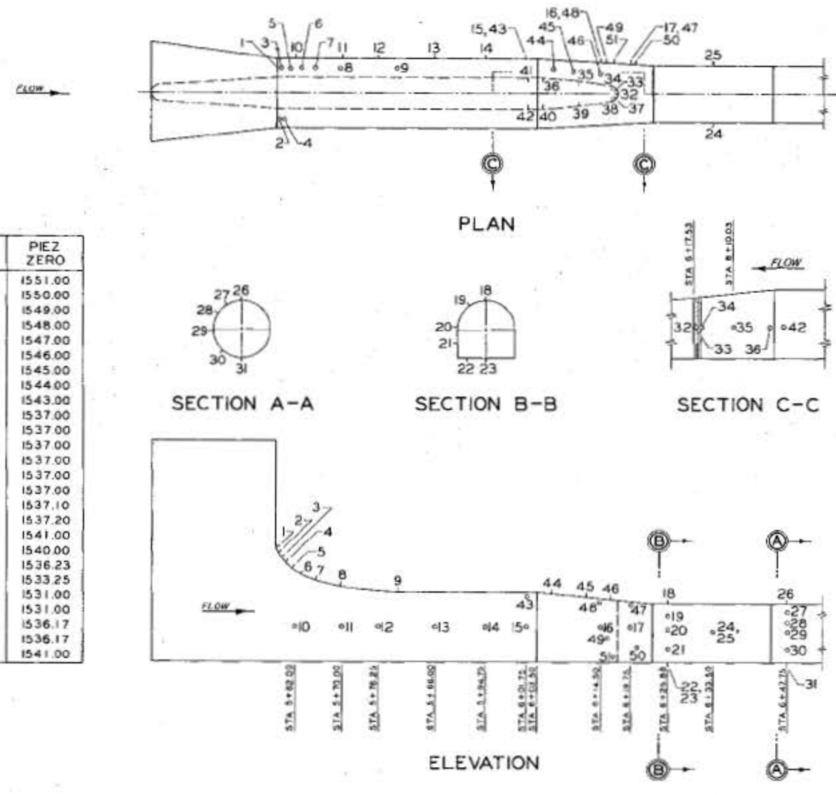
FLOW CHARACTERISTICS

TYPE D1 DISPERSAL BUCKET

DISCHARGE = 70,000 CFS

SCALE IN FEET

100 0 100 200 300 400 500

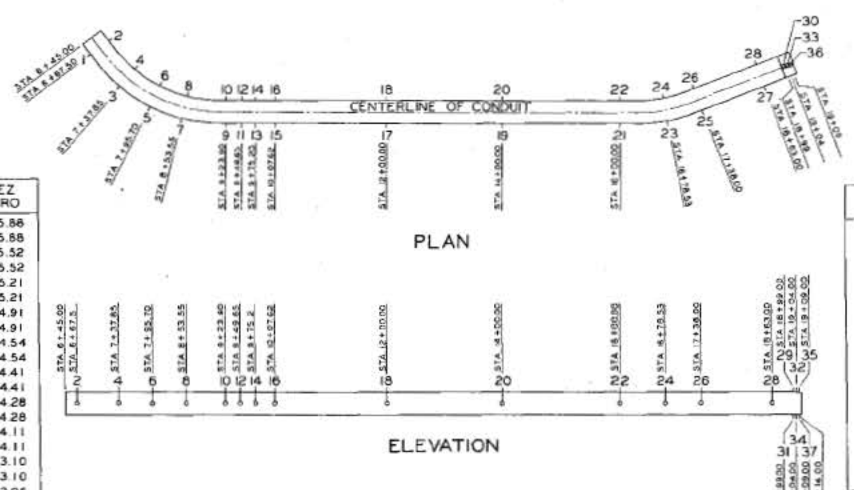


PIEZ NO	PIEZ ZERO
1	1551.00
2	1550.00
3	1549.00
4	1548.00
5	1547.00
6	1546.00
7	1545.00
8	1544.00
9	1543.00
10	1537.00
11	1537.00
12	1537.00
13	1537.00
14	1537.00
15	1537.00
16	1537.10
17	1537.20
18	1541.00
19	1540.00
20	1536.23
21	1533.25
22	1531.00
23	1531.00
24	1536.17
25	1536.17
26	1541.00

PIEZ NO	PIEZ ZERO
27	1540.18
28	1538.82
29	1535.52
30	1532.25
31	1531.00
32	1536.38
33	1536.38
34	1536.38
35	1536.38
36	1536.38
37	1536.38
38	1536.38
39	1536.38
40	1536.38
41	1537.00
42	1537.00
43	1542.25
44	1542.75
45	1542.45
46	1541.75
47	1540.50
48	1541.25
49	1535.50
50	1533.75
51	1532.25

INTAKE STRUCTURE

SCALE 100 0 100 200 FT



PIEZ NO	PIEZ ZERO
1	1535.88
2	1535.88
3	1535.52
4	1535.52
5	1535.21
6	1535.21
7	1534.91
8	1534.91
9	1534.54
10	1534.54
11	1534.41
12	1534.41
13	1534.28
14	1534.28
15	1534.11
16	1534.11
17	1533.10
18	1533.10
19	1532.06

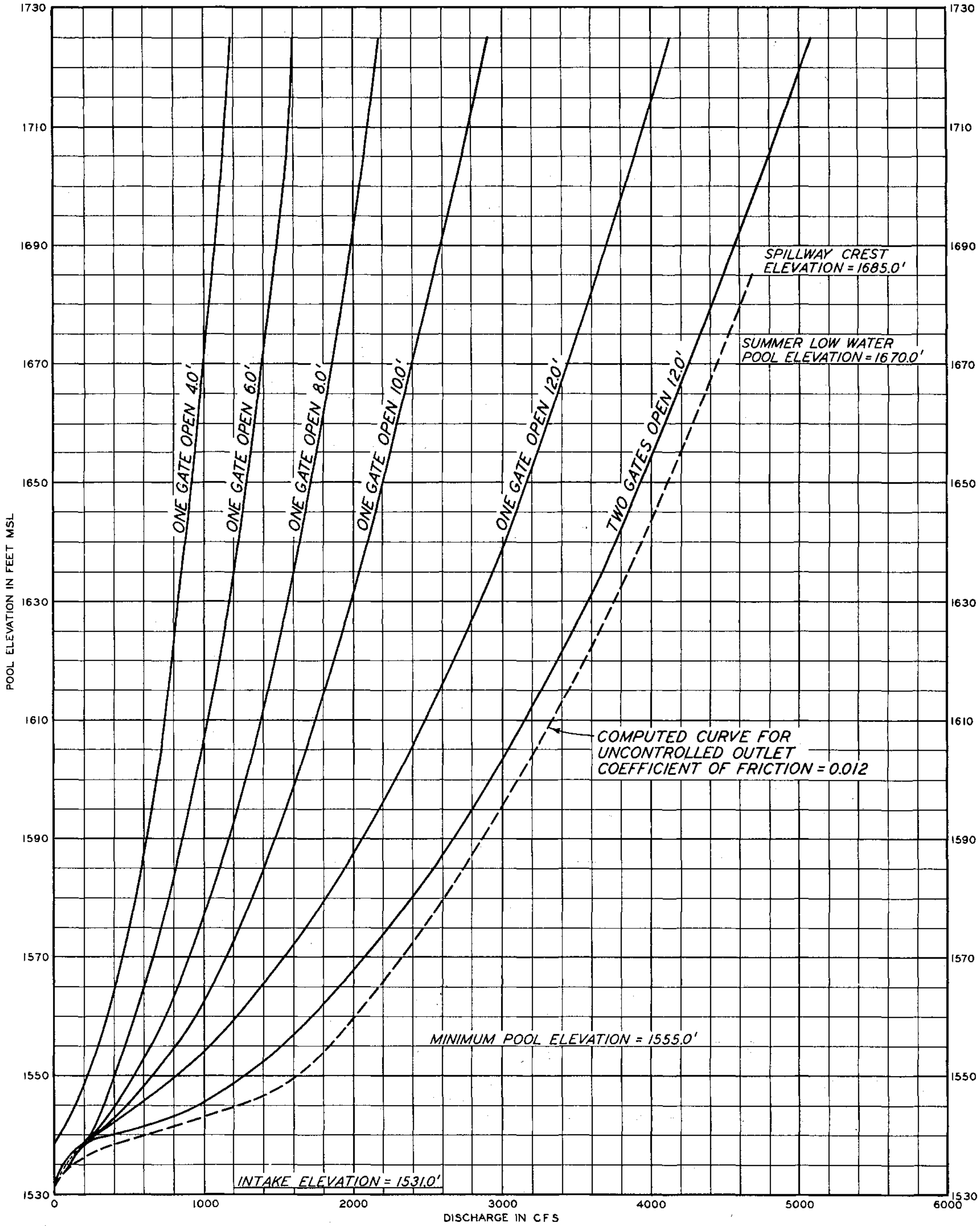
PIEZ NO	PIEZ ZERO
20	1532.06
21	1531.02
22	1531.02
23	1530.61
24	1530.61
25	1530.30
26	1530.30
27	1529.64
28	1529.64
29	1534.22
30	1529.20
31	1524.46
32	1533.97
33	1529.00
34	1524.43
35	1533.71
36	1520.70
37	1524.41

CONDUIT

SCALE 100 0 100 200 FT

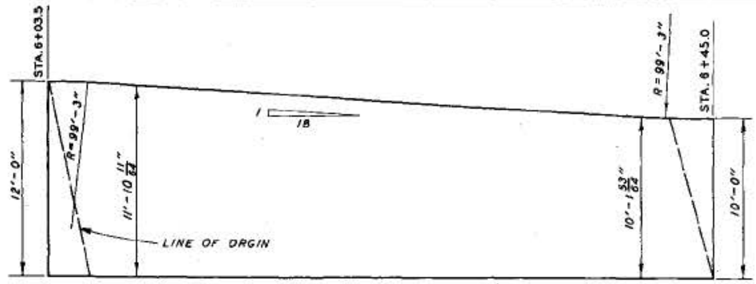
PIEZOMETER LOCATIONS OUTLET WORKS

SCALES AS SHOWN

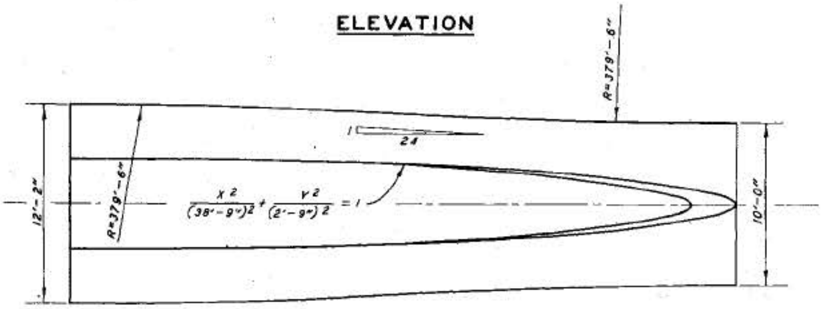


DISCHARGE CURVES

FULL AND PARTIAL GATE OPENINGS

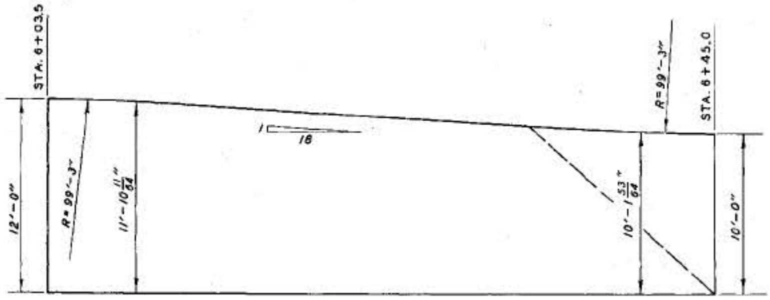


ELEVATION

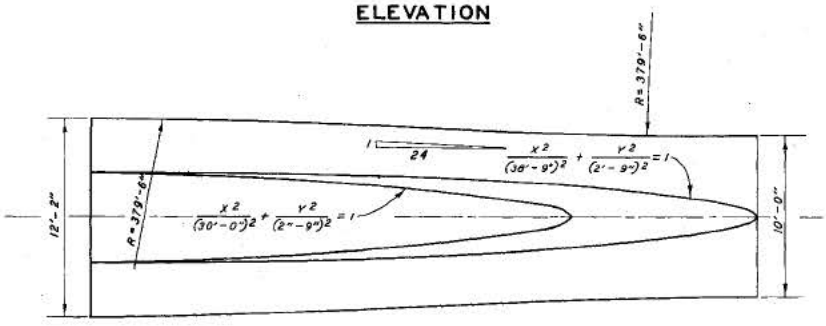


PLAN

TYPE A



ELEVATION

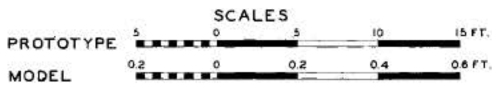


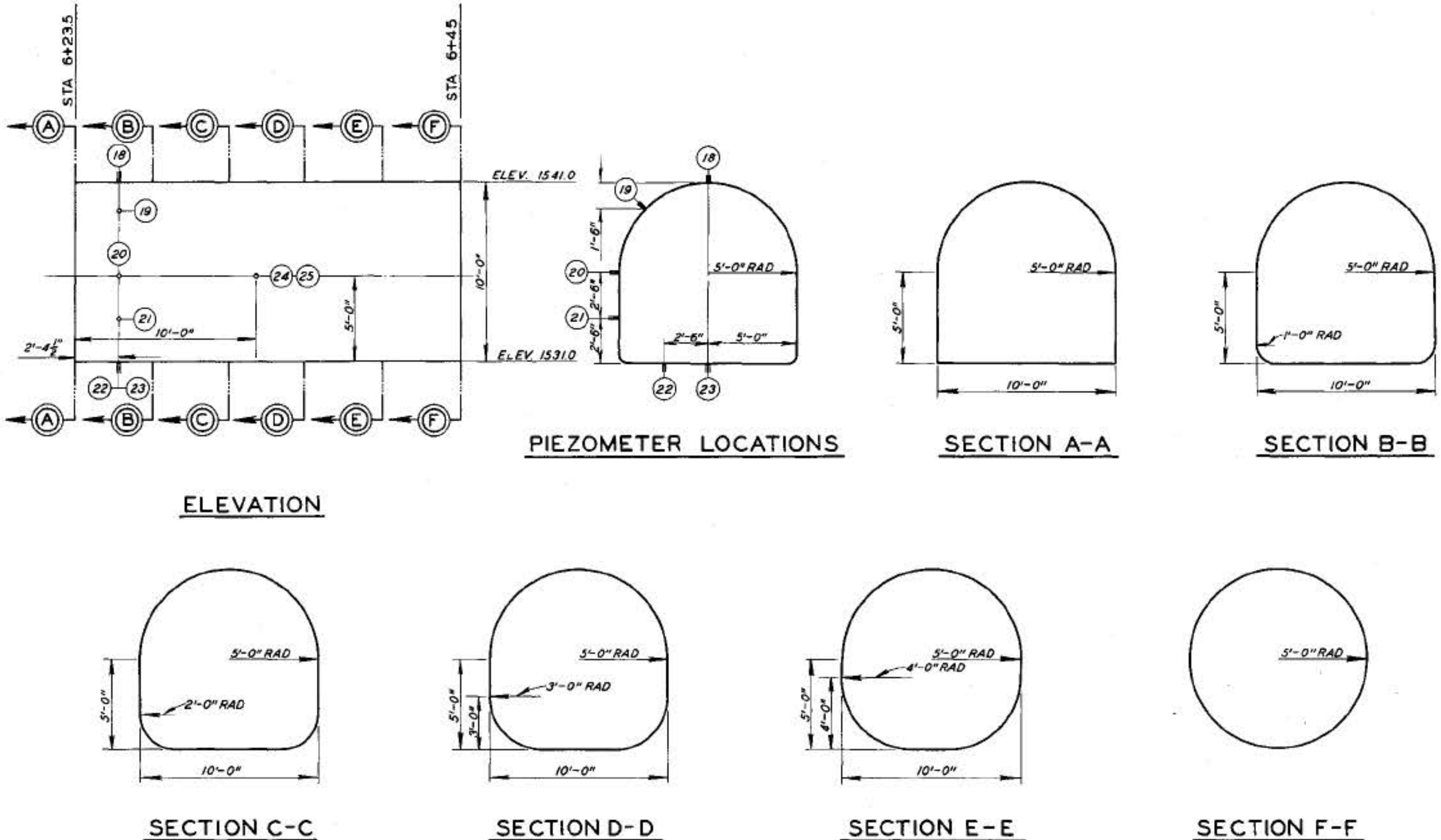
PLAN

TYPE B

NOTE: ALL DIMENSIONS ARE IN PROTOTYPE UNITS.

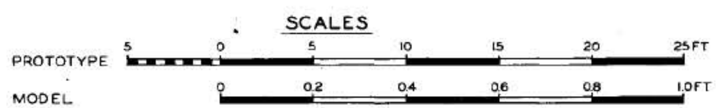
OUTLET WORKS
TRANSITION SECTIONS
TYPES A AND B





NOTE: ALL DIMENSIONS ARE IN PROTOTYPE UNITS.

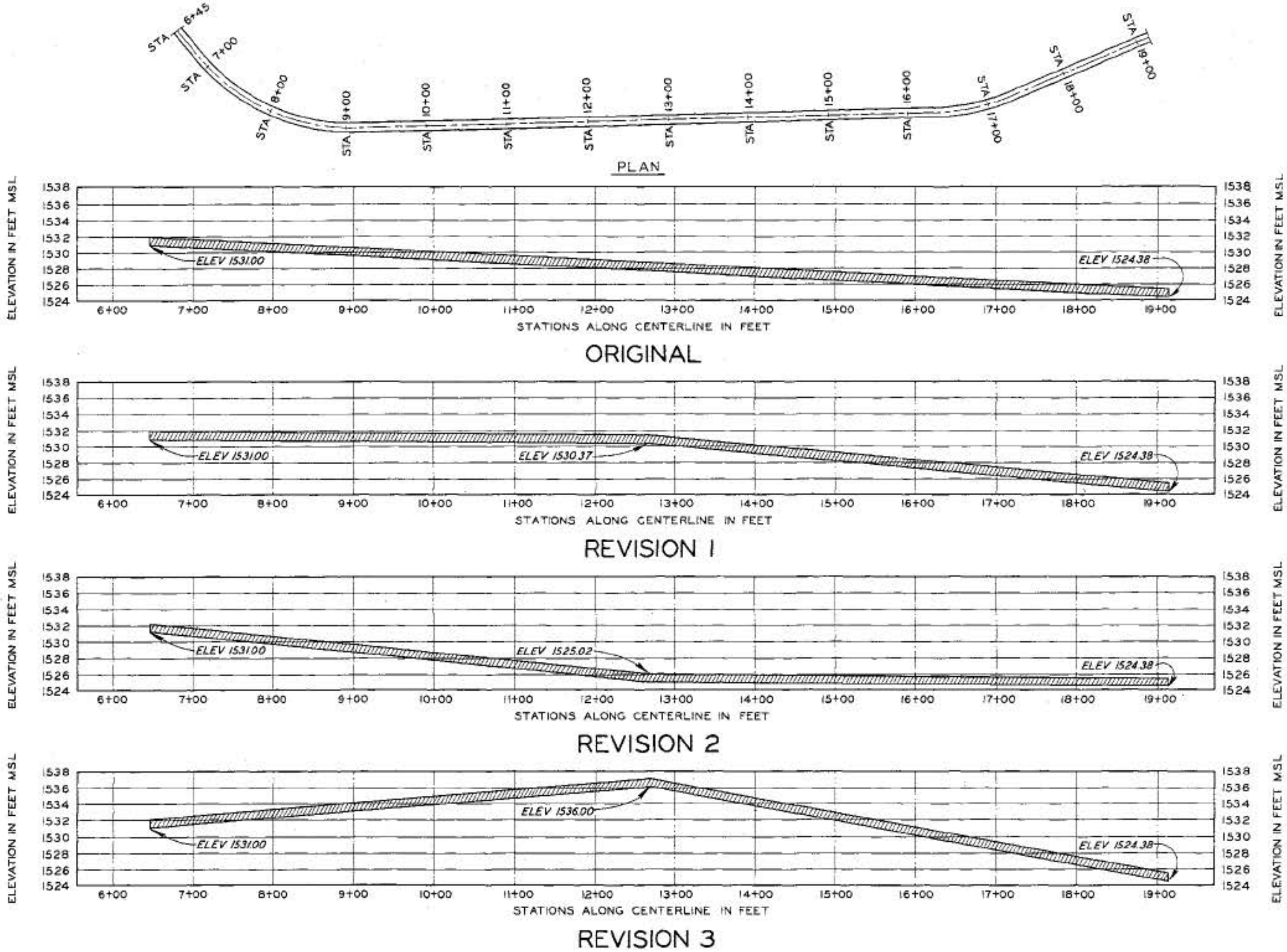
PIEZOMETER LOCATIONS SHOWN THUS (20)



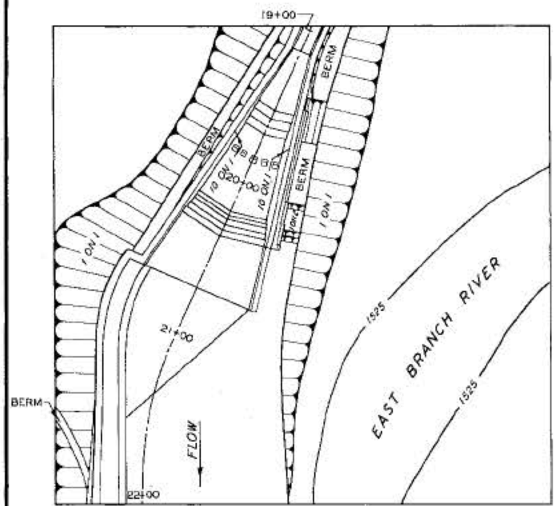
OUTLET WORKS TRANSITION SECTION

TYPE C

PLATE 28



REVISIONS OF GRADE
OUTLET WORKS CONDUIT



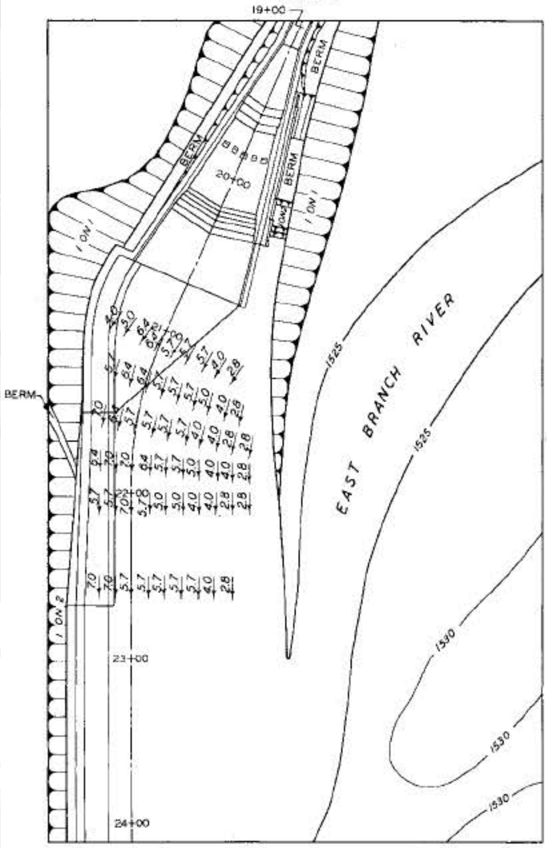
PLAN

MODEL CONDITIONS

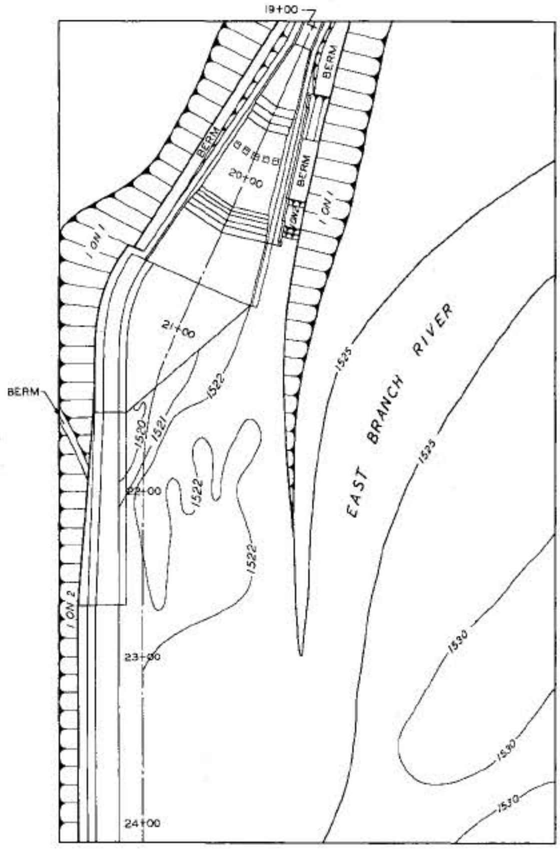
I ROW OF BAFFLES
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 0 FT

FLOW CONDITIONS

DISCHARGE	2500 CFS
TAILWATER ELEVATION	1528.5 FT



BOTTOM VELOCITIES



SCOUR PATTERN

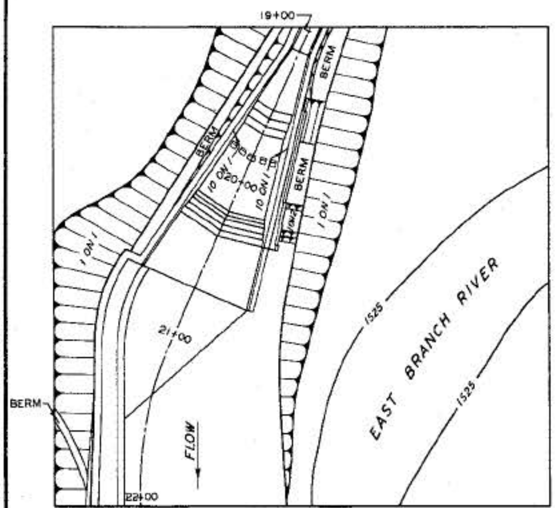
VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

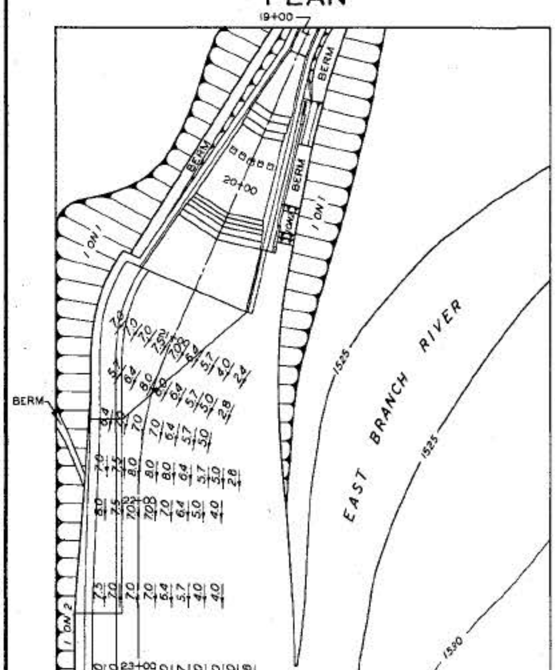
ORIGINAL DESIGN
DISCHARGE 2500 CFS

SCALE IN FEET
50 0 50 100 150

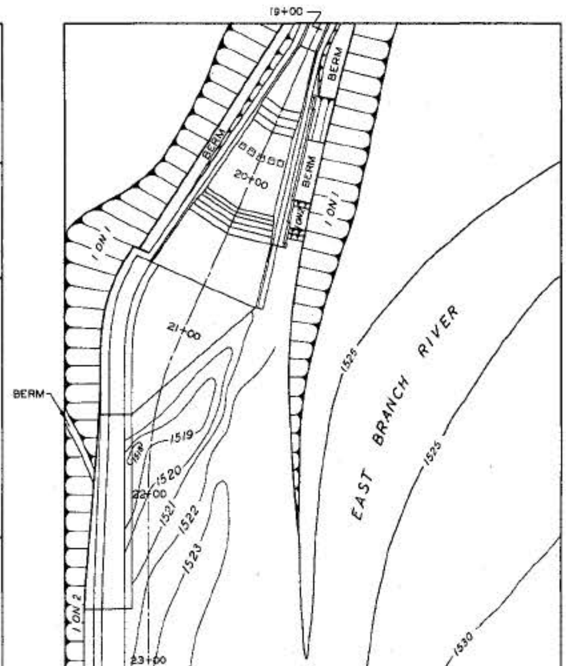
NOTE: ALL VALUES IN PROTOTYPE UNITS.



PLAN



BOTTOM VELOCITIES



SCOUR PATTERN

MODEL CONDITIONS

1 ROW OF BAFFLES
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 0 FT

FLOW CONDITIONS

DISCHARGE	3500 CFS
TAILWATER ELEVATION	1529.5 FT

VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

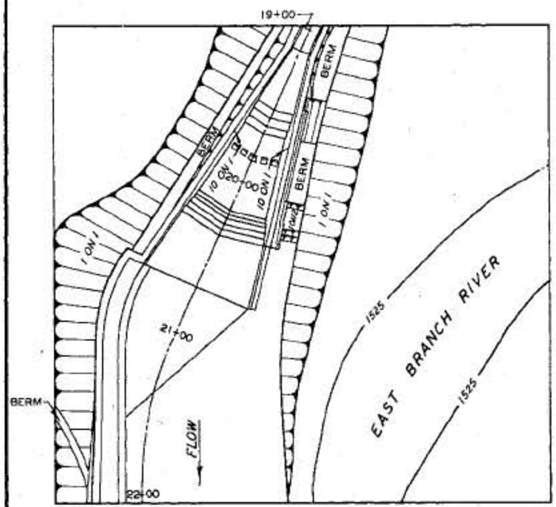
ORIGINAL DESIGN

DISCHARGE 3500 CFS

SCALE IN FEET

50 0 50 100 150

NOTE: ALL VALUES IN PROTOTYPE UNITS.



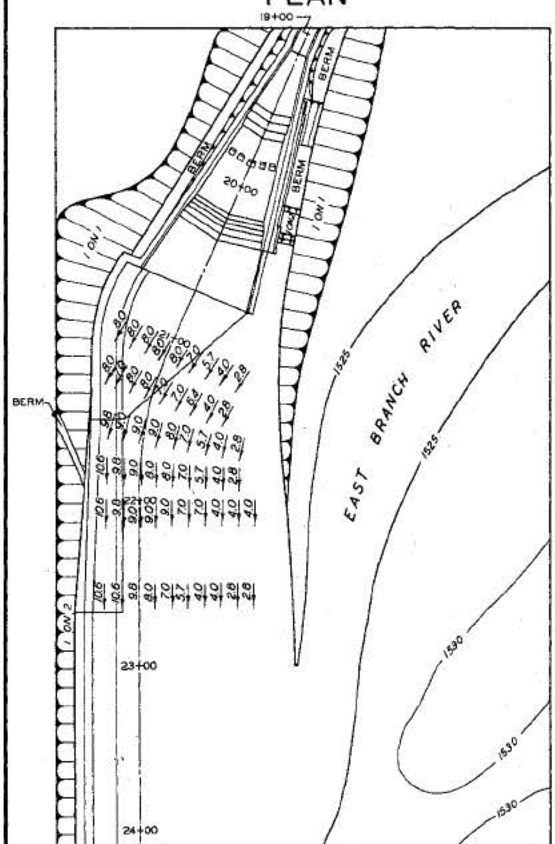
PLAN

MODEL CONDITIONS

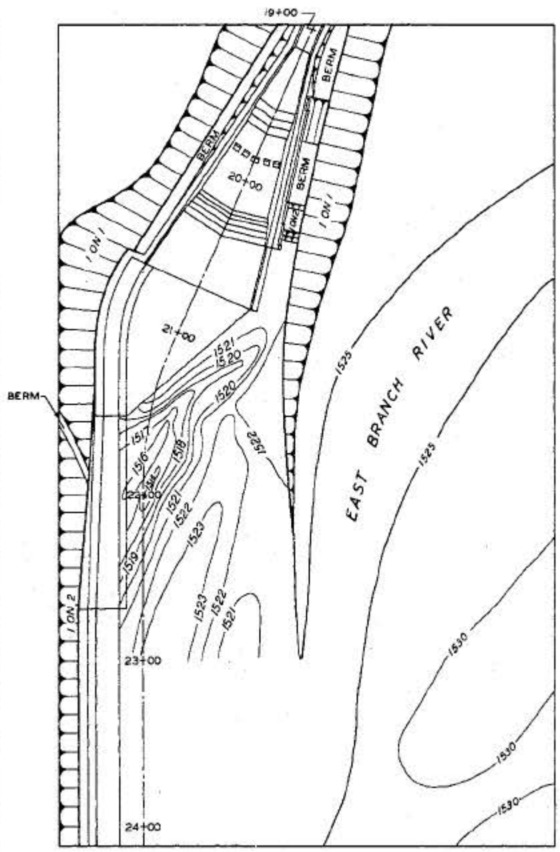
1 ROW OF BAFFLES
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 0 FT

FLOW CONDITIONS

DISCHARGE	5000 CFS
TAILWATER ELEVATION	1531.0 FT



BOTTOM VELOCITIES



SCOUR PATTERN

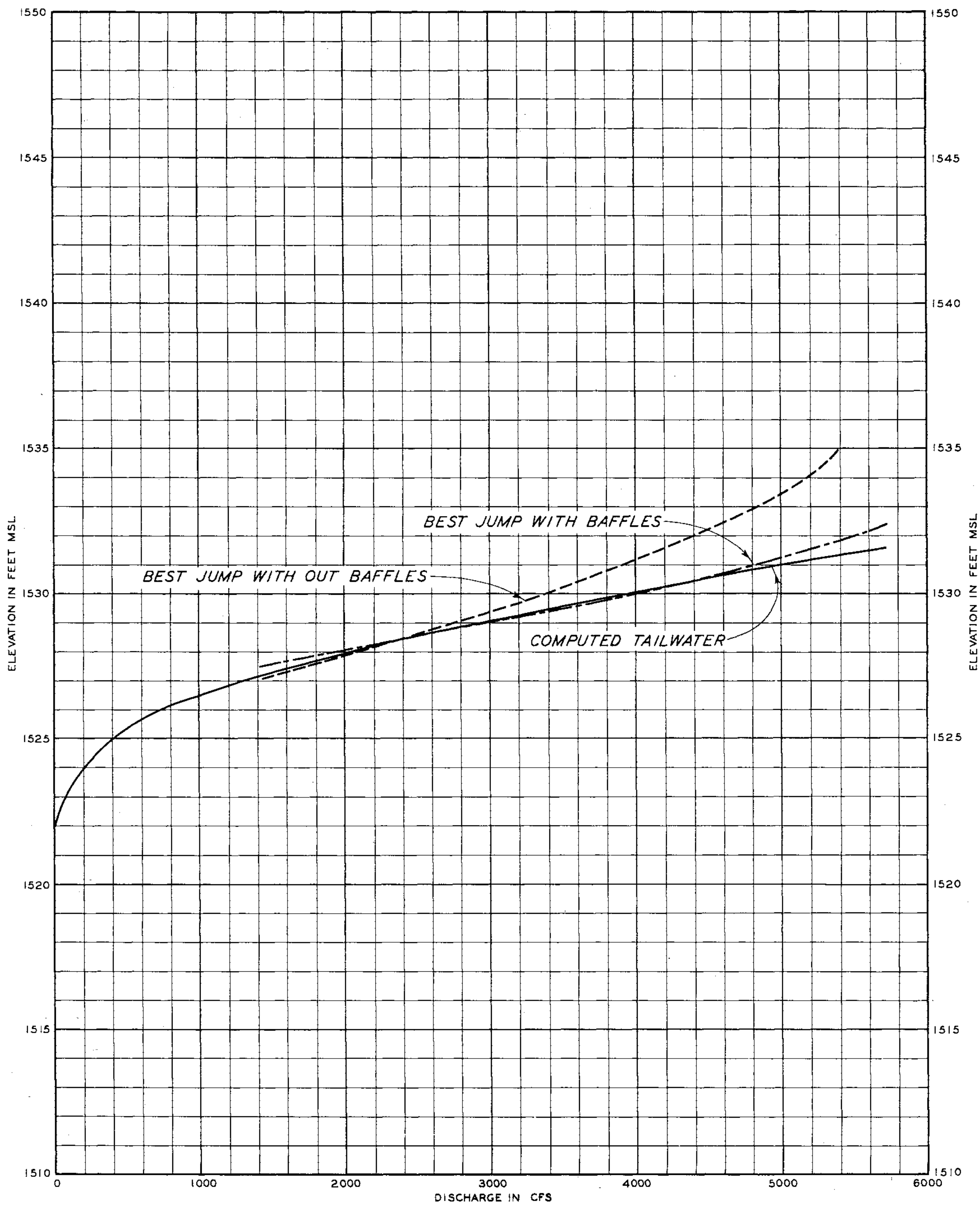
VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

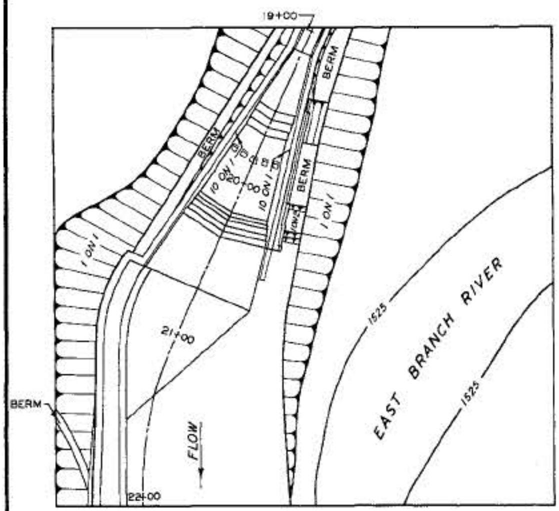
ORIGINAL DESIGN
DISCHARGE 5000 CFS

SCALE IN FEET
50 0 50 100 150

NOTE: ALL VALUES IN PROTOTYPE UNITS.



TAILWATER CURVES



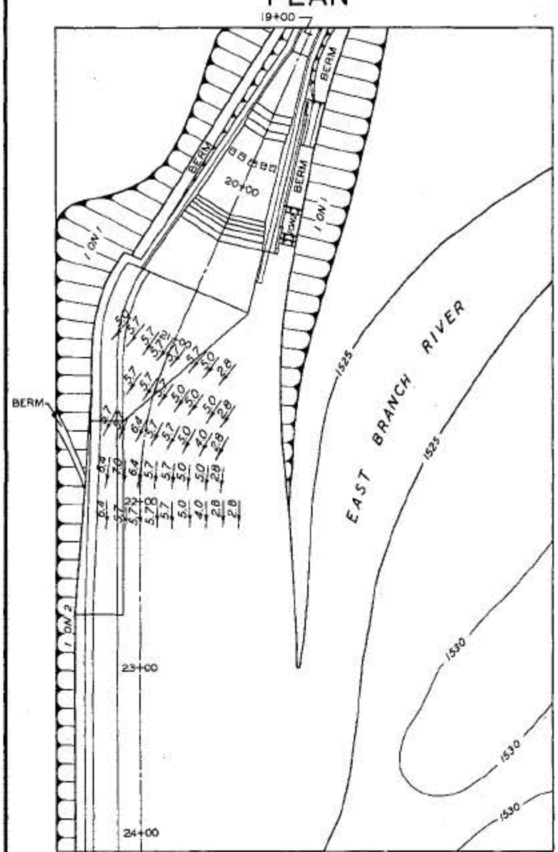
PLAN

MODEL CONDITIONS

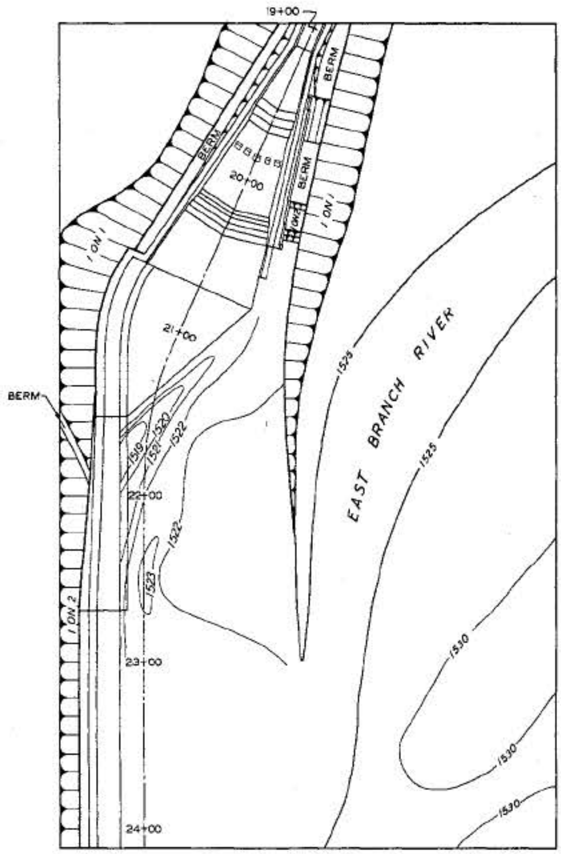
I ROW OF BAFFLES
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 20 FT

FLOW CONDITIONS

DISCHARGE	2500 CFS
TAILWATER ELEVATION	1528.5 FT



BOTTOM VELOCITIES



SCOUR PATTERN

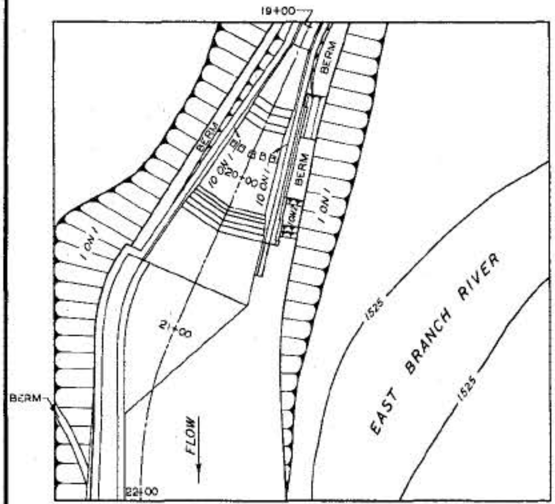
VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

LEFT TRAINING WALL CUT 20 FT
DISCHARGE 2500 CFS

SCALE IN FEET
50 0 50 100 150

NOTE: ALL VALUES IN PROTOTYPE UNITS.



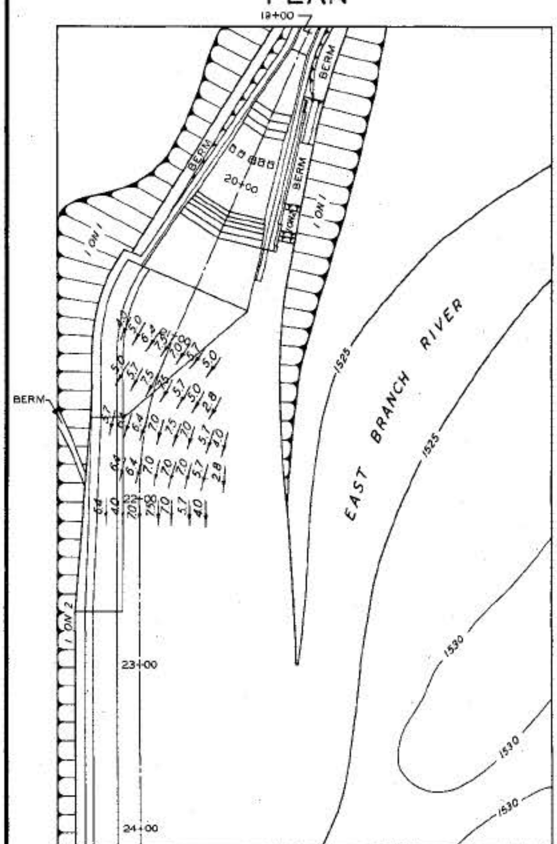
PLAN

MODEL CONDITIONS

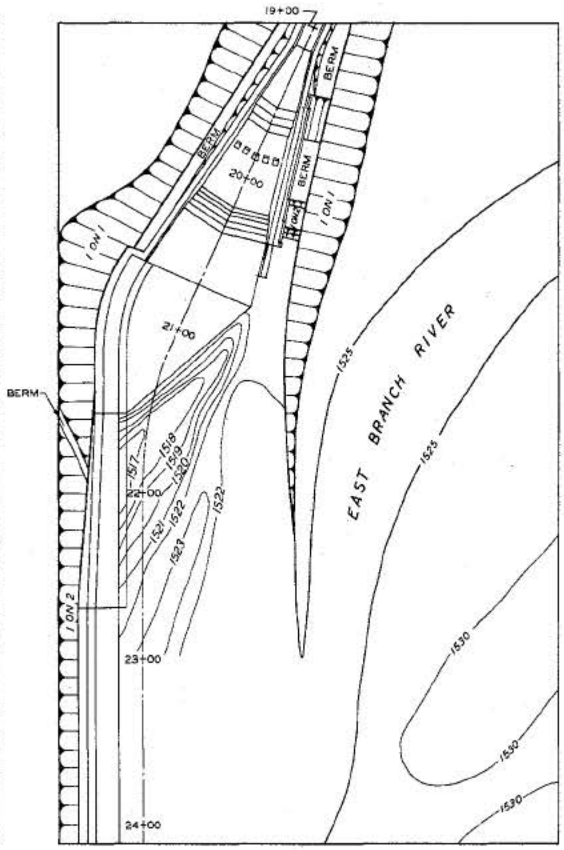
1 ROW OF BAFFLES
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 20 FT

FLOW CONDITIONS

DISCHARGE 3500 CFS
TAILWATER ELEVATION 1529.5 FT



BOTTOM VELOCITIES



SCOUR PATTERN

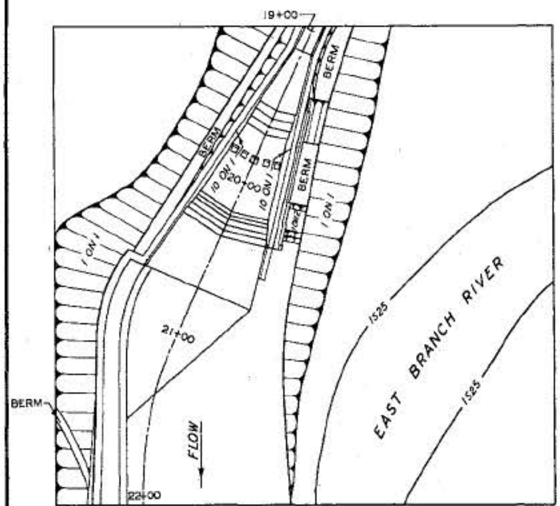
VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

LEFT TRAINING WALL CUT 20 FT
DISCHARGE 3500 CFS

SCALE IN FEET
50 0 50 100 150

NOTE: ALL VALUES IN PROTOTYPE UNITS.



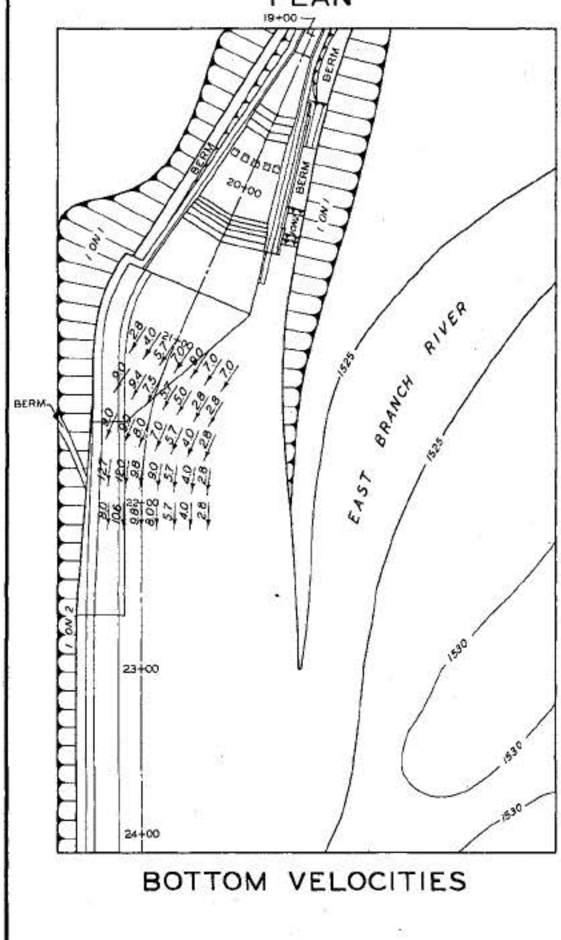
MODEL CONDITIONS

1 ROW OF BAFFLES
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 20 FT

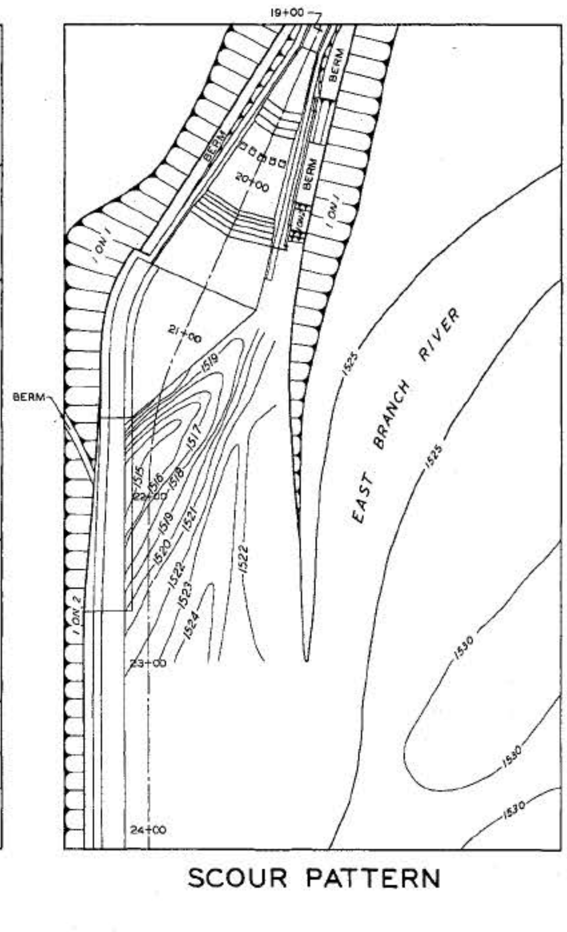
FLOW CONDITIONS

DISCHARGE	5000 CFS
TAILWATER ELEVATION	1531.0 FT

PLAN



BOTTOM VELOCITIES



SCOUR PATTERN

VELOCITIES AND SCOUR

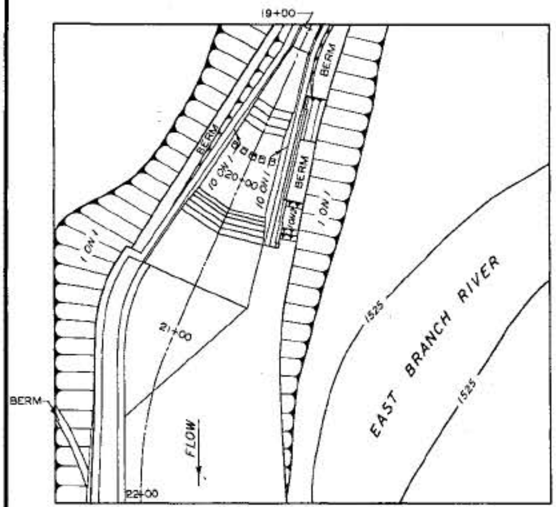
STILLING BASIN AND OUTLET CHANNEL

LEFT TRAINING WALL CUT 20 FT
DISCHARGE 5000 CFS

SCALE IN FEET

50 0 50 100 150

NOTE: ALL VALUES IN PROTOTYPE UNITS.



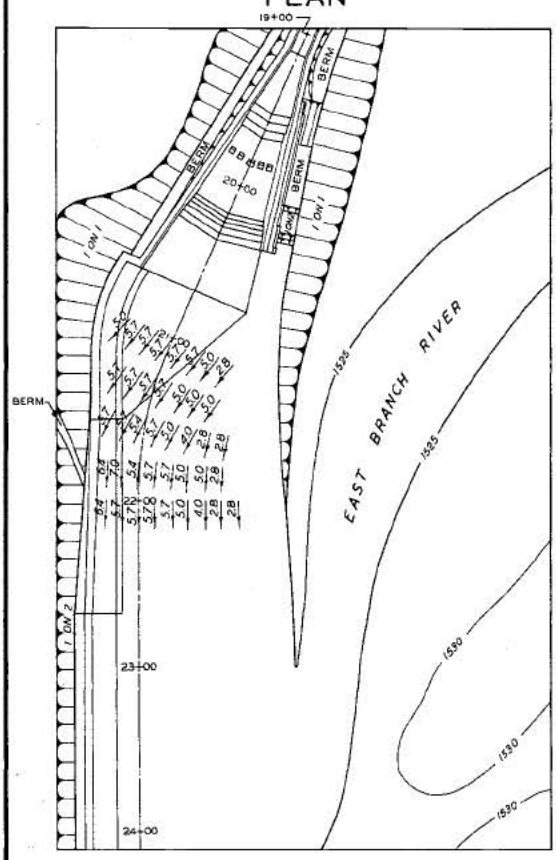
PLAN

MODEL CONDITIONS

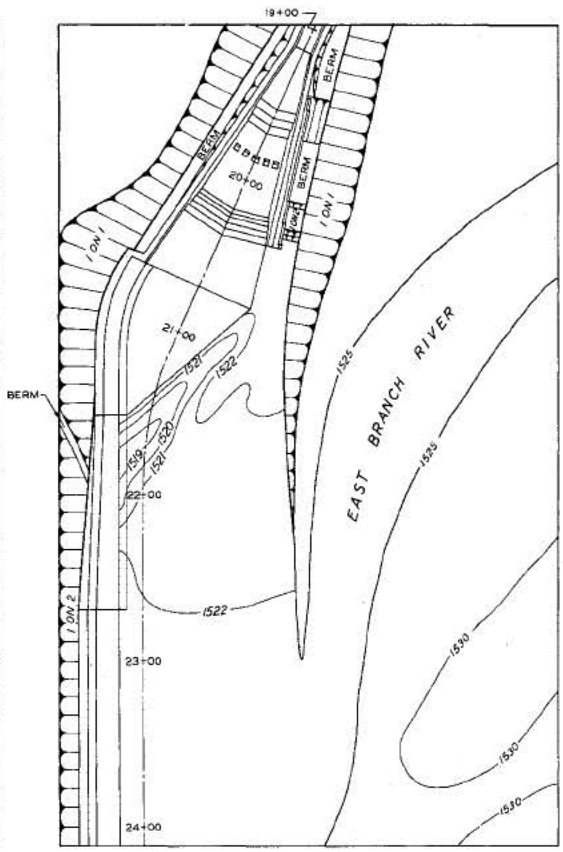
1 ROW OF BAFFLES
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 40 FT

FLOW CONDITIONS

DISCHARGE	2500 CFS
TAILWATER ELEVATION	1528.5 FT



BOTTOM VELOCITIES



SCOUR PATTERN

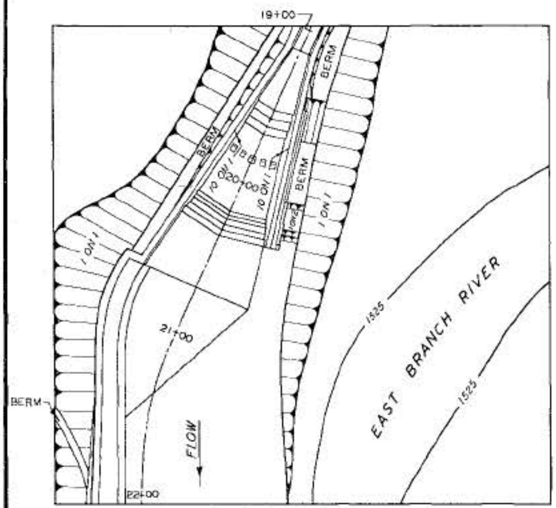
VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

LEFT TRAINING WALL CUT 40 FT
DISCHARGE 2500 CFS

SCALE IN FEET
50 0 50 100 150

NOTE: ALL VALUES IN PROTOTYPE UNITS.



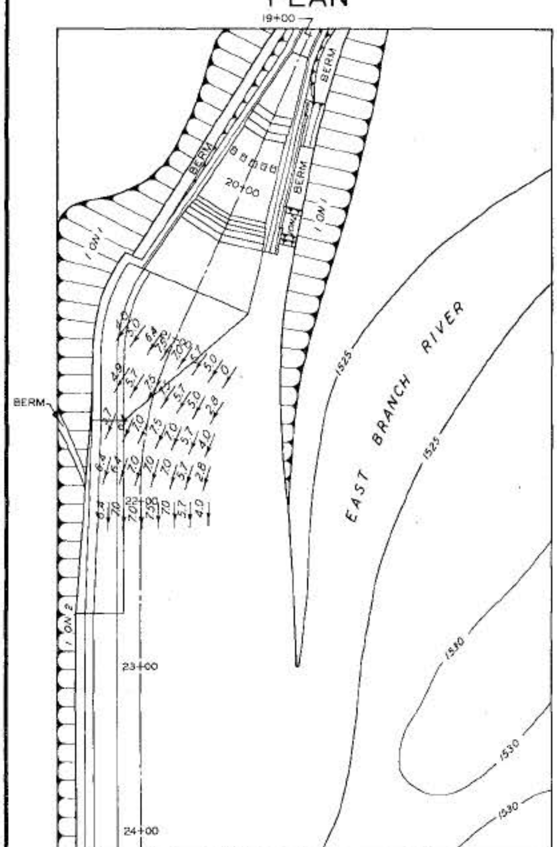
PLAN

MODEL CONDITIONS

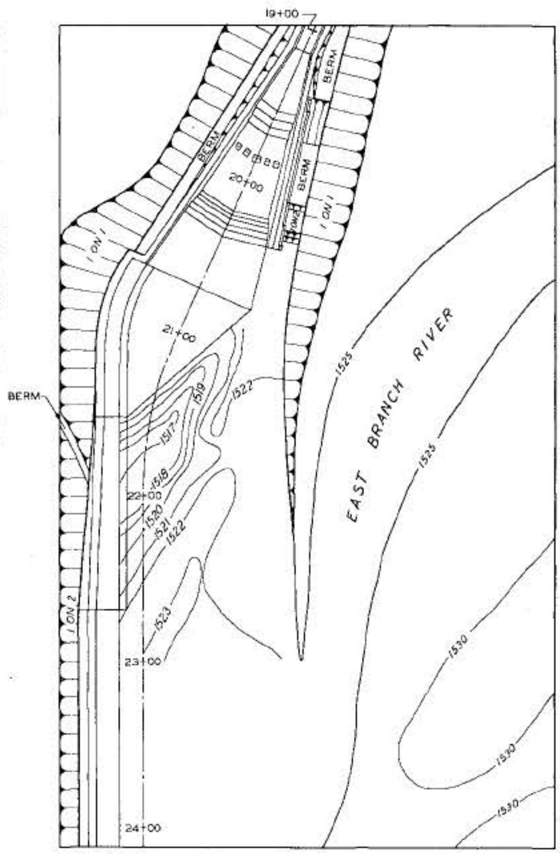
1 ROW OF BAFFLES
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 40 FT

FLOW CONDITIONS

DISCHARGE	3500 CFS
TAILWATER ELEVATION	1529.5 FT



BOTTOM VELOCITIES



SCOUR PATTERN

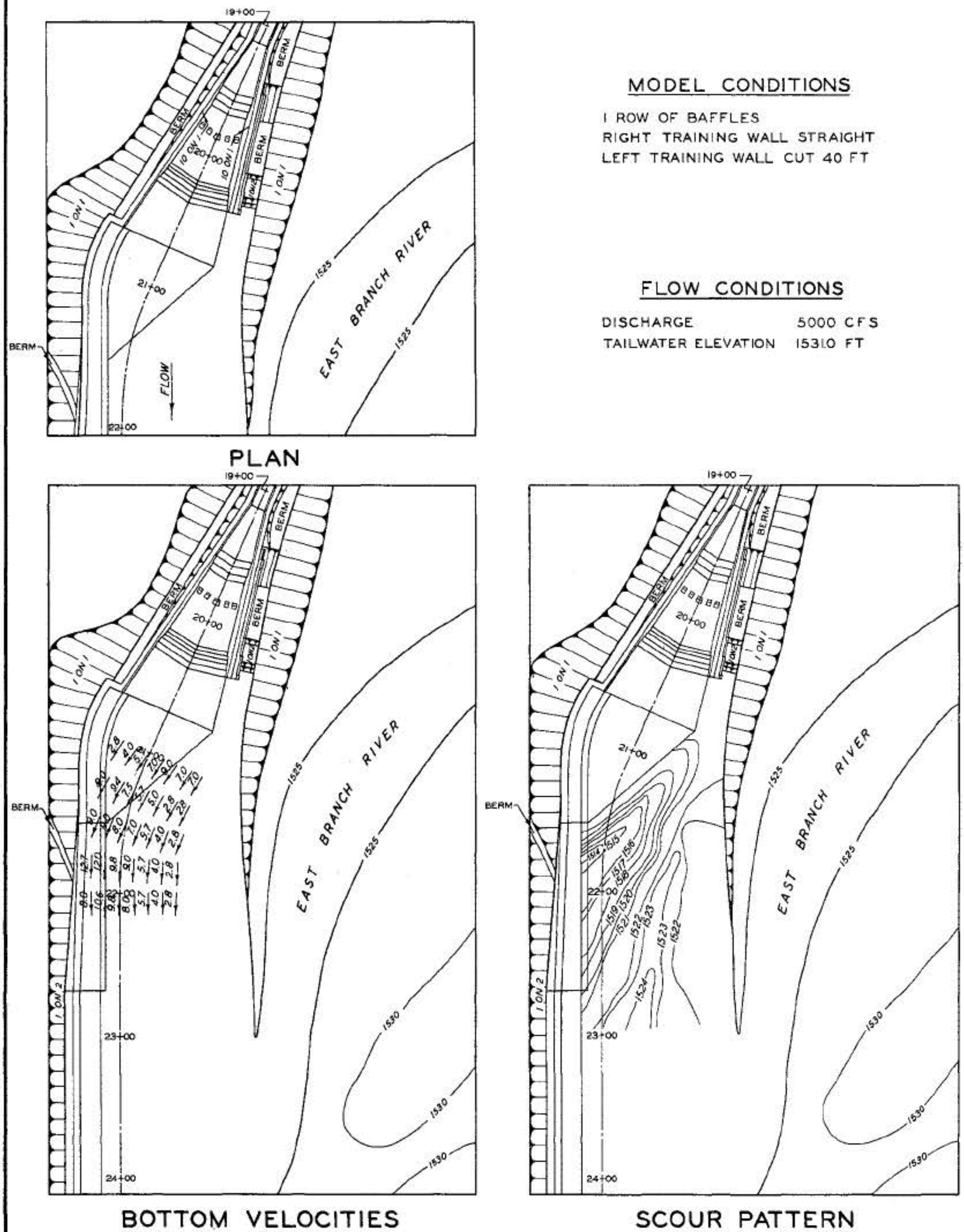
VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

LEFT TRAINING WALL CUT 40 FT
DISCHARGE 3500 CFS

SCALE IN FEET
50 0 50 100 150

NOTE: ALL VALUES IN PROTOTYPE UNITS.



MODEL CONDITIONS

1 ROW OF BAFFLES
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 40 FT

FLOW CONDITIONS

DISCHARGE	5000 CFS
TAILWATER ELEVATION	1531.0 FT

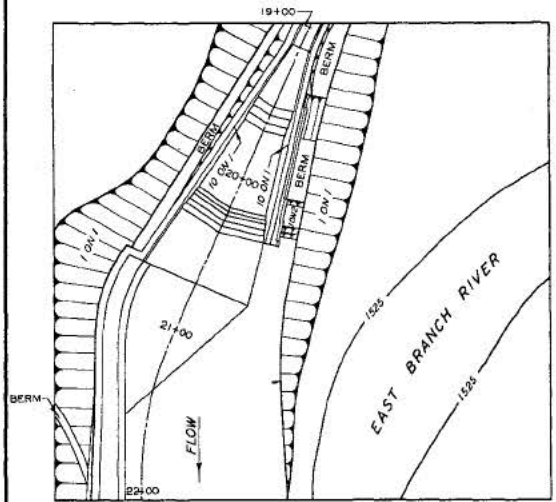
VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

LEFT TRAINING WALL CUT 40 FT
DISCHARGE 5000 CFS

SCALE IN FEET
50 0 50 100 150

NOTE: ALL VALUES IN PROTOTYPE UNITS.



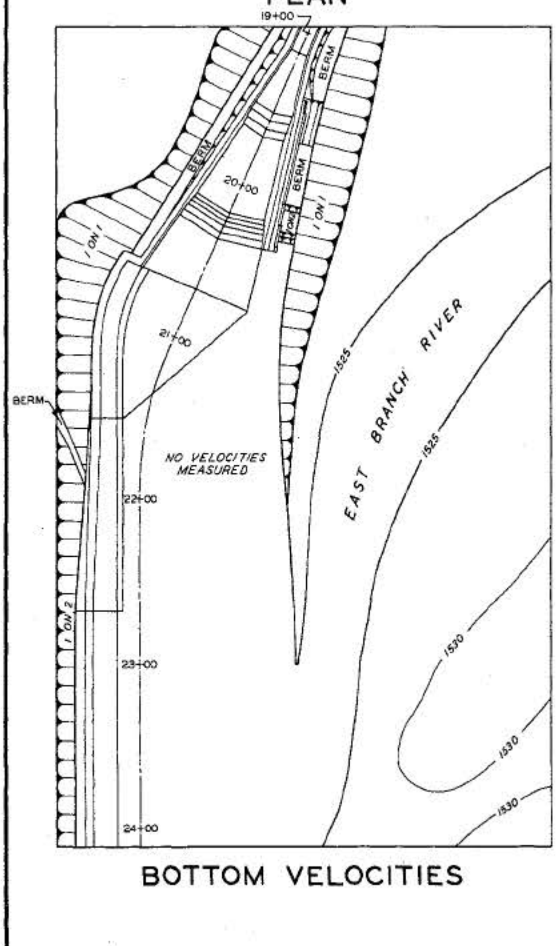
PLAN

MODEL CONDITIONS

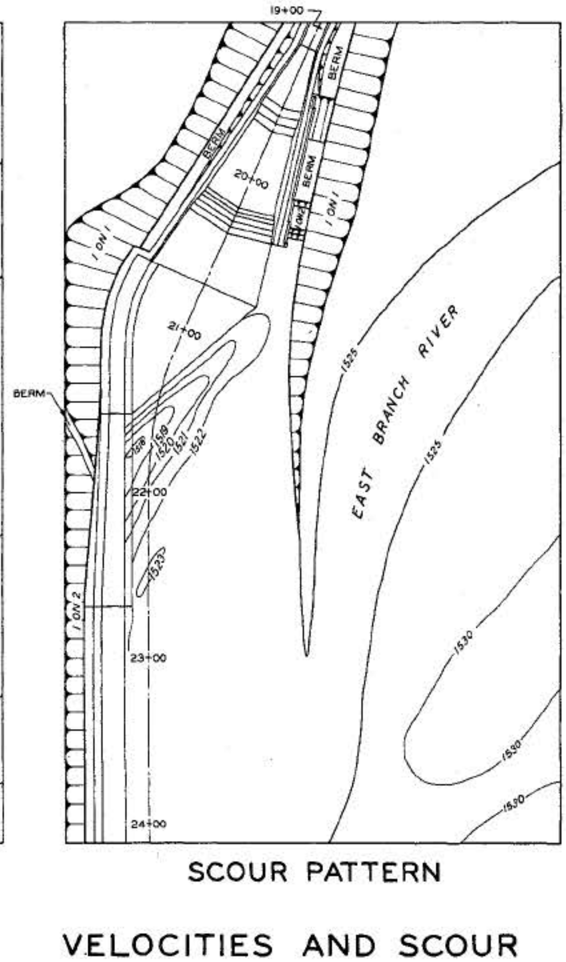
NO BAFFLES
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 40 FT

FLOW CONDITIONS

DISCHARGE	2500 CFS
TAILWATER ELEVATION	1528.50 FT



BOTTOM VELOCITIES



SCOUR PATTERN

VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

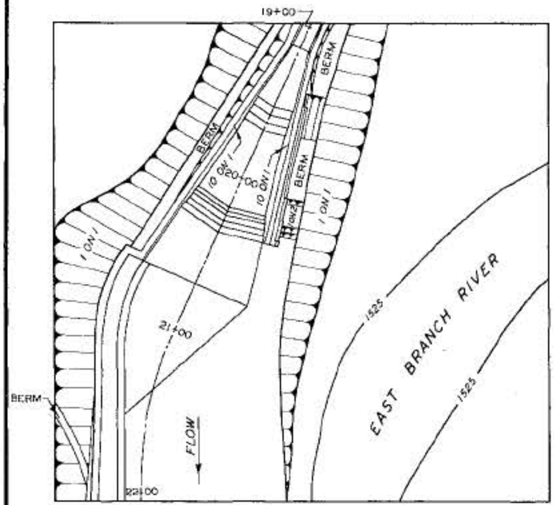
ALL BAFFLES REMOVED

DISCHARGE 2500 CFS

SCALE IN FEET

50 0 50 100 150

NOTE: ALL VALUES IN PROTOTYPE UNITS.



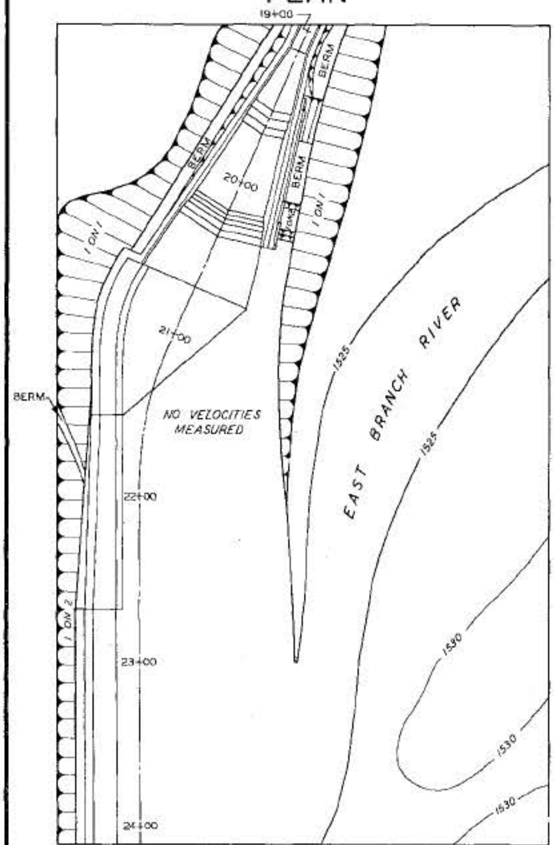
PLAN

MODEL CONDITIONS

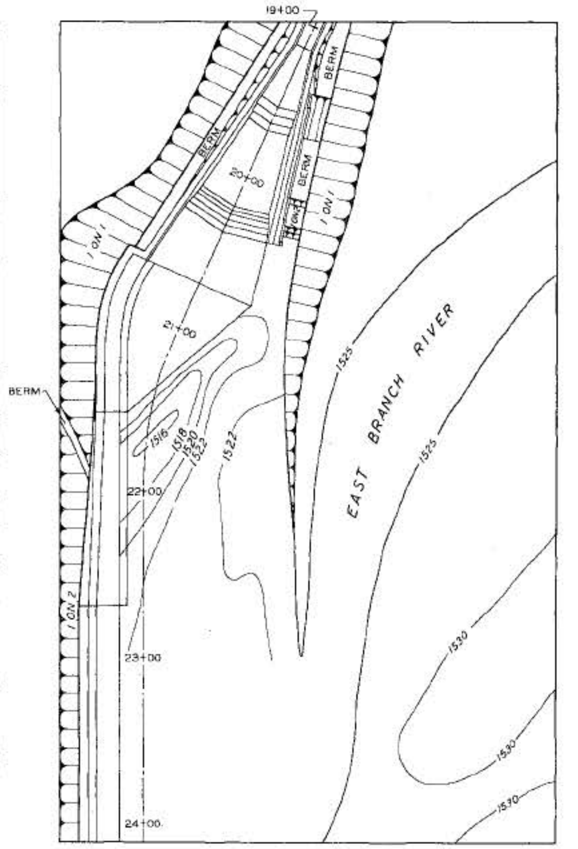
NO BAFFLES
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 40 FT

FLOW CONDITIONS

DISCHARGE	3500 CFS
TAILWATER ELEVATION	1529.5 FT



BOTTOM VELOCITIES



SCOUR PATTERN

VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

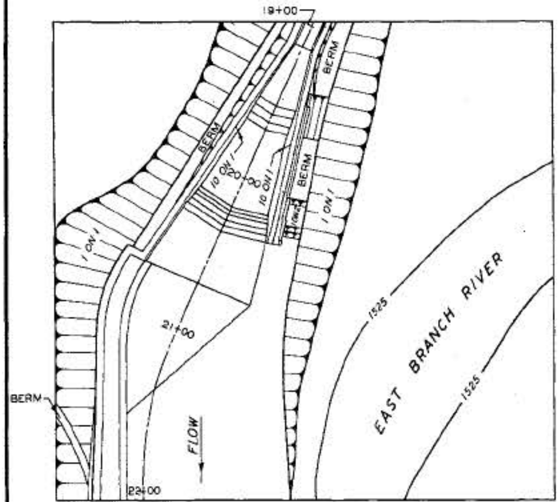
ALL BAFFLES REMOVED

DISCHARGE 3500 CFS

SCALE IN FEET

50 0 50 100 150

NOTE: ALL VALUES IN PROTOTYPE UNITS.



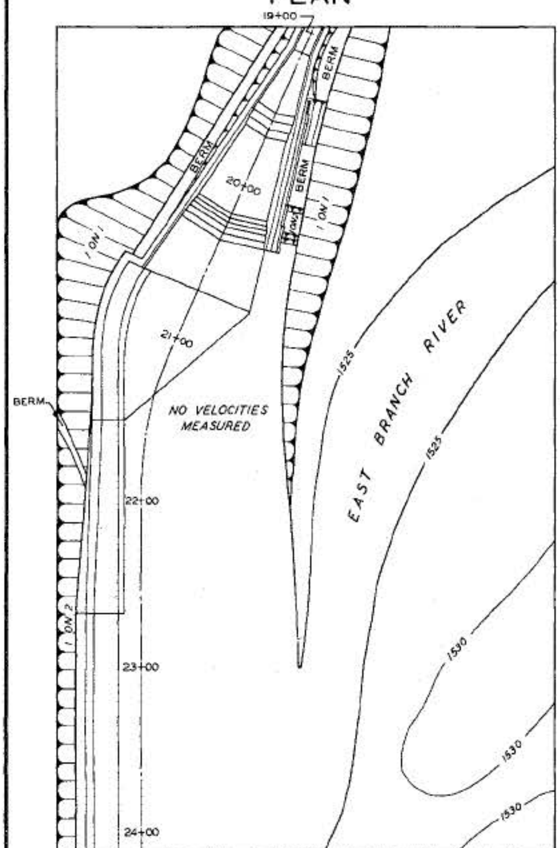
PLAN

MODEL CONDITIONS

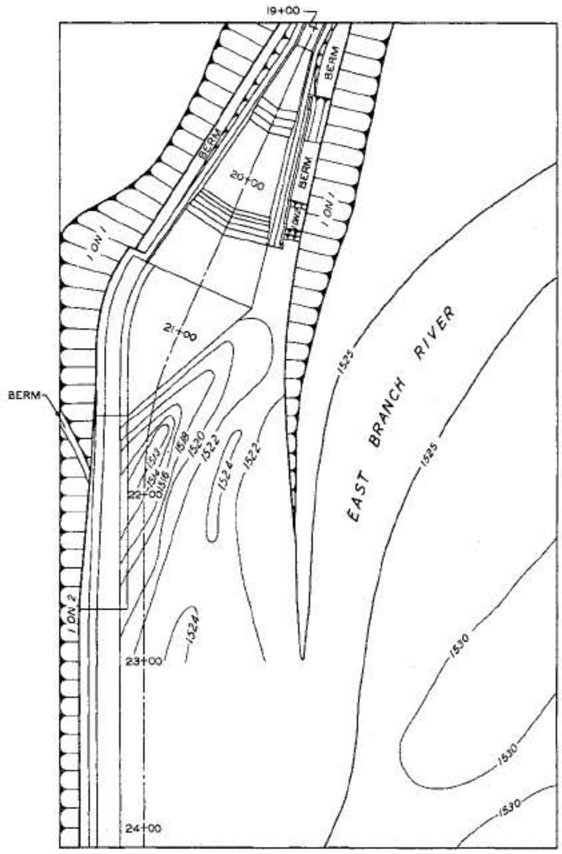
NO BAFFLES
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 40 FT

FLOW CONDITIONS

DISCHARGE	5000 CFS
TAILWATER ELEVATION	1531.0 FT



BOTTOM VELOCITIES



SCOUR PATTERN

VELOCITIES AND SCOUR

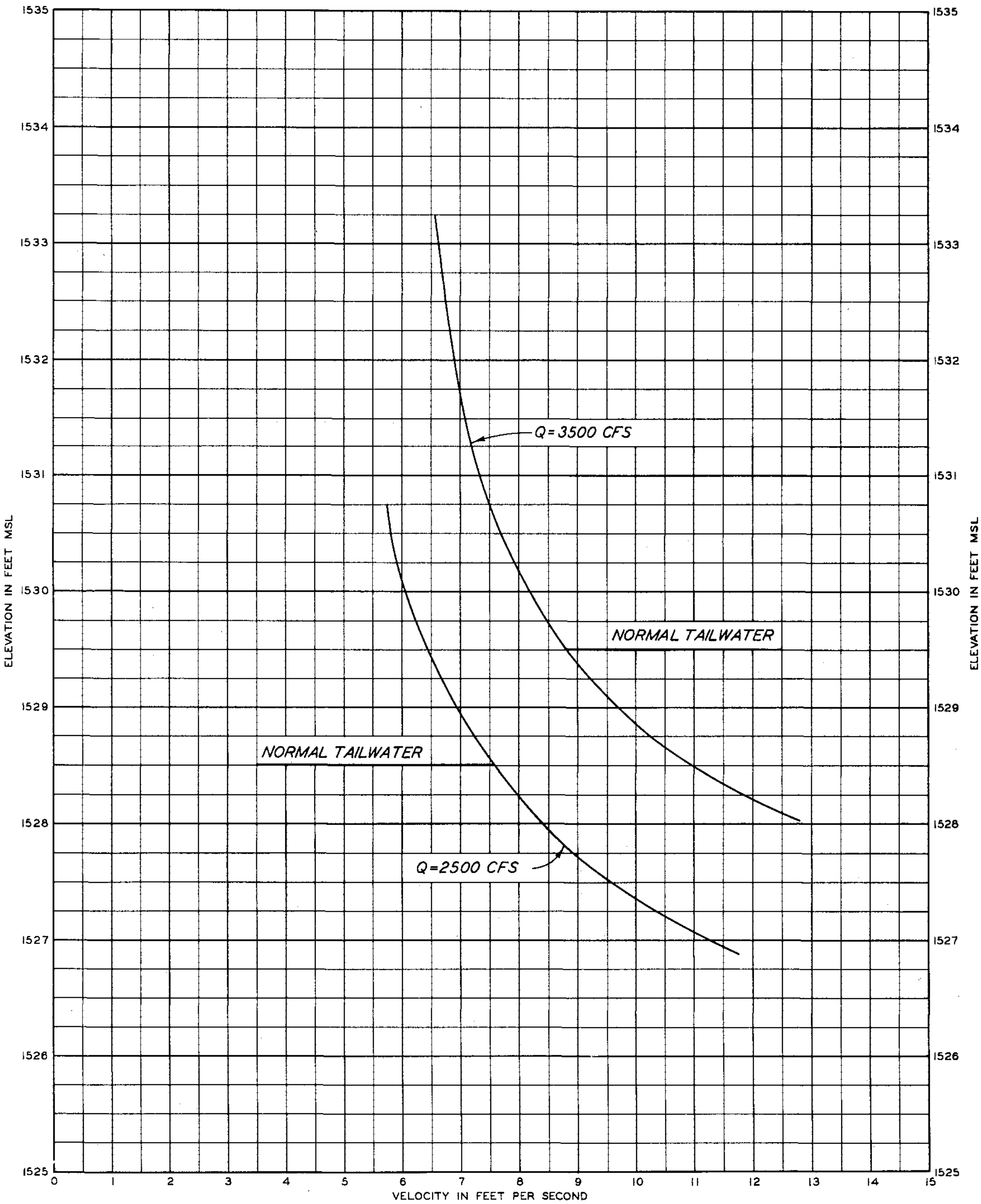
STILLING BASIN AND OUTLET CHANNEL

ALL BAFFLES REMOVED
DISCHARGE 5000 CFS

NOTE: ALL VALUES IN PROTOTYPE UNITS.

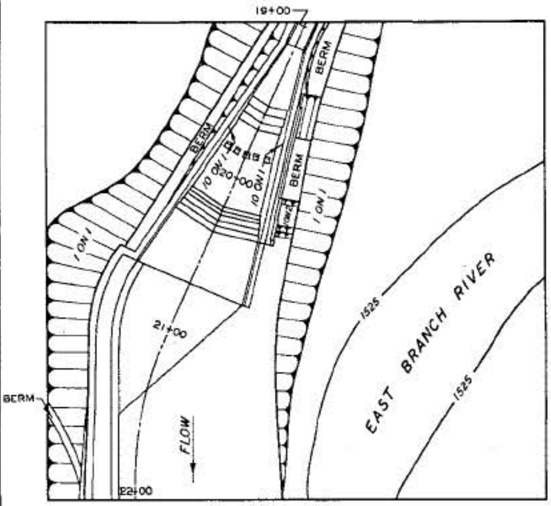
SCALE IN FEET

50 0 50 100 150



NOTE: ALL BAFFLES REMOVED.
LEFT TRAINING WALL CUT 40 FT.

OUTLET WORKS
END SILL VELOCITIES



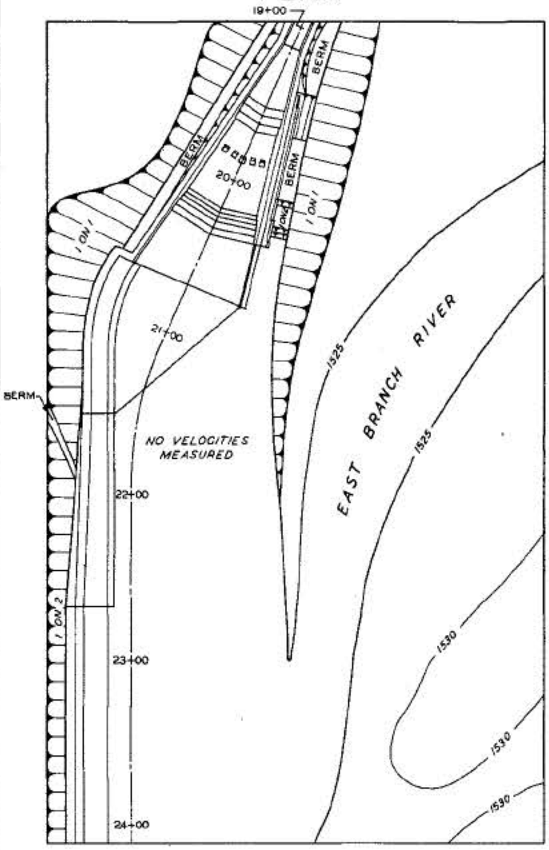
PLAN

MODEL CONDITIONS

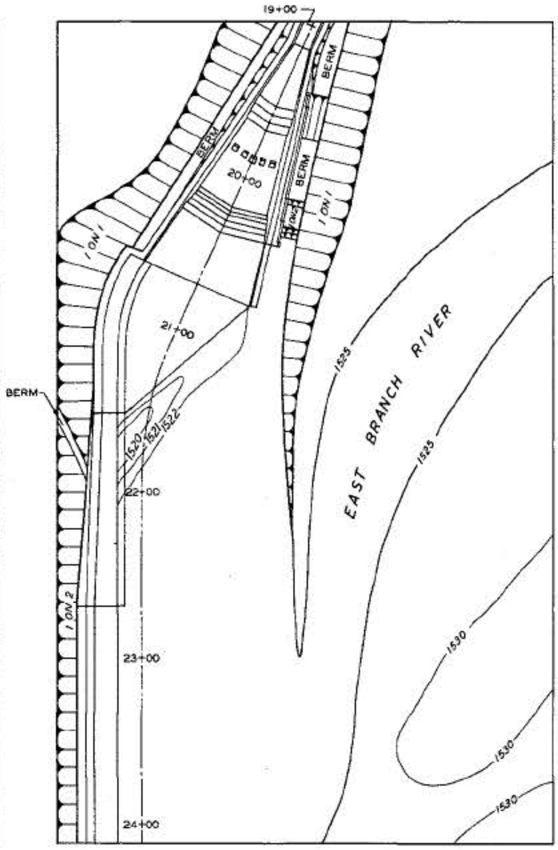
1 ROW OF BAFFLES DOWNSTREAM 2 FT
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 0 FT

FLOW CONDITIONS

DISCHARGE 2500 CFS
TAILWATER ELEVATION 1528.50 FT



BOTTOM VELOCITIES



SCOUR PATTERN

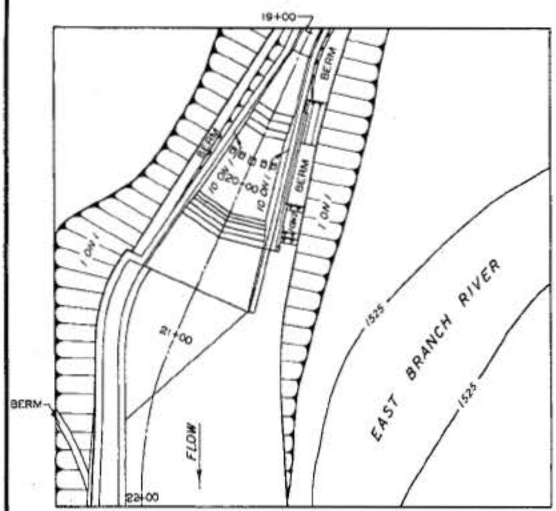
VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

BAFFLES MOVED DOWNSTREAM
DISCHARGE 2500 CFS

SCALE IN FEET
50 0 50 100 150

NOTE: ALL VALUES IN PROTOTYPE UNITS.



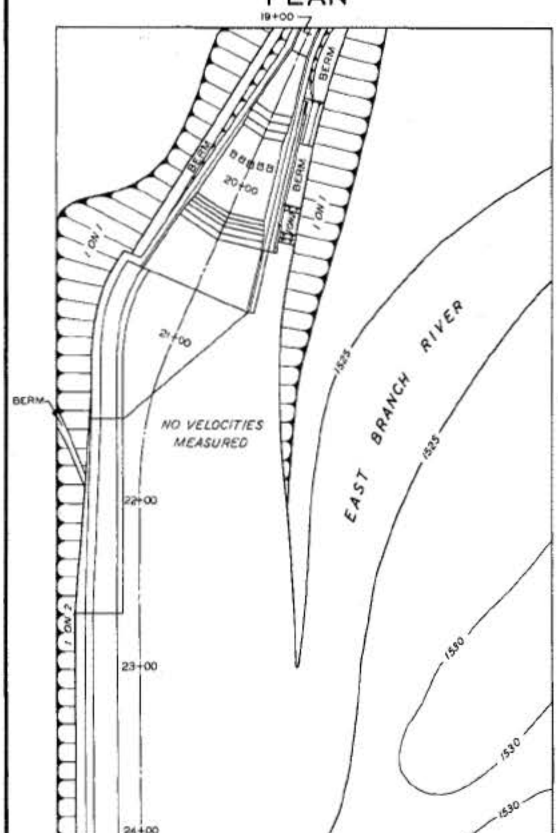
PLAN

MODEL CONDITIONS

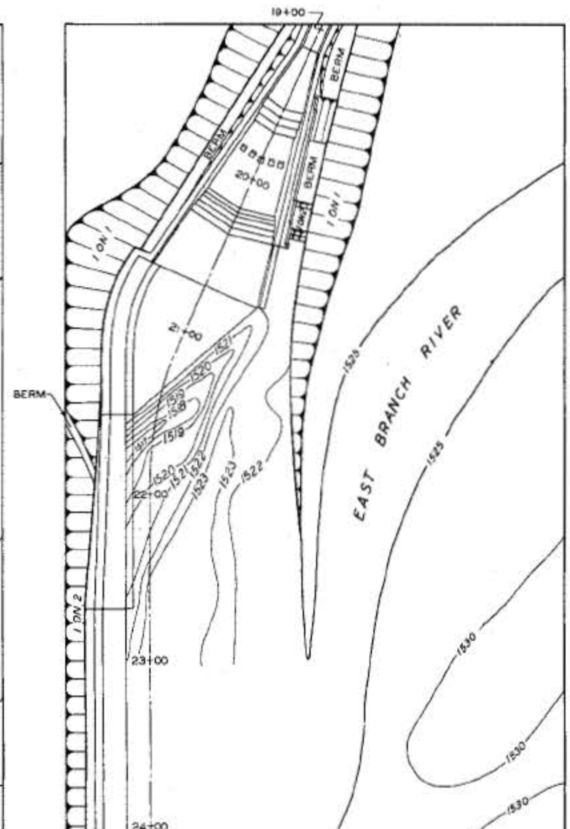
I ROW OF BAFFLES DOWNSTREAM 2 FT
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 0 FT

FLOW CONDITIONS

DISCHARGE	3500 CFS
TAILWATER ELEVATION	1529.5 FT



BOTTOM VELOCITIES



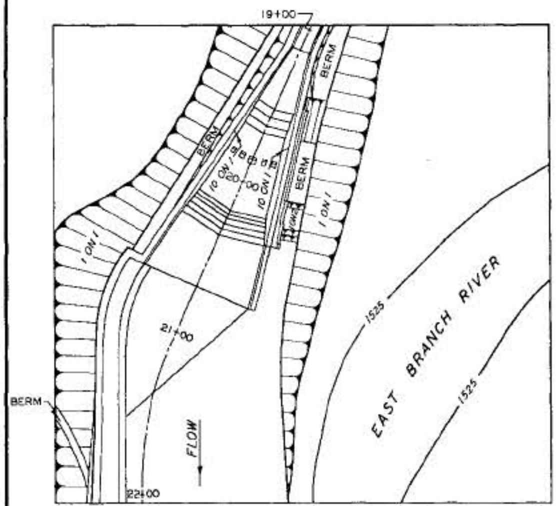
SCOUR PATTERN

VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

BAFFLES MOVED DOWNSTREAM
DISCHARGE 3500 CFS
SCALE IN FEET
50 0 50 100 150

NOTE: ALL VALUES IN PROTOTYPE UNITS.



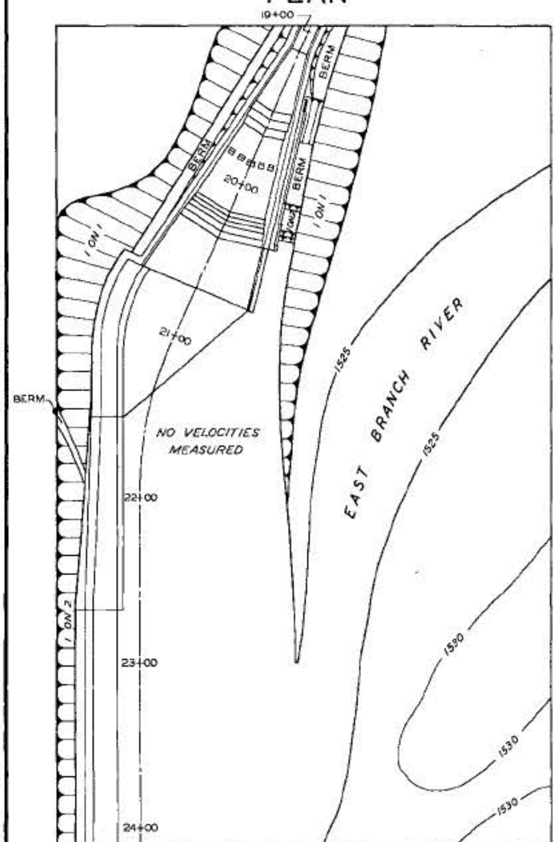
PLAN

MODEL CONDITIONS

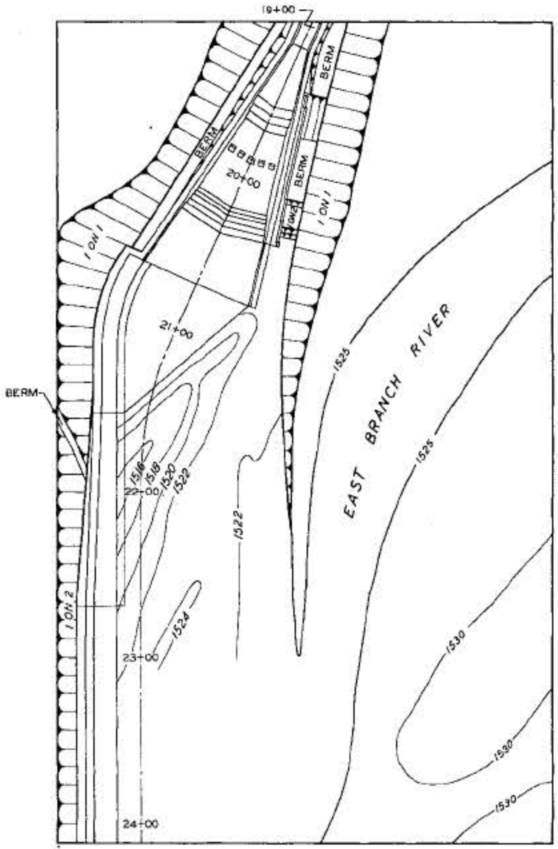
1 ROW OF BAFFLES DOWNSTREAM 2 FT
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 0 FT

FLOW CONDITIONS

DISCHARGE 5000 CFS
TAILWATER ELEVATION 1531.0 FT



BOTTOM VELOCITIES



SCOUR PATTERN

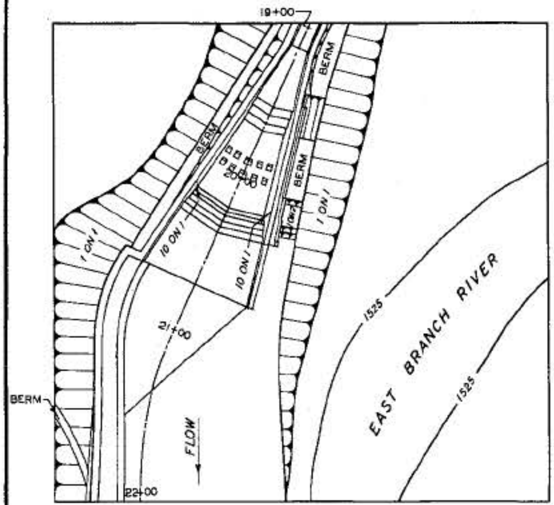
VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

BAFFLES MOVED DOWNSTREAM
DISCHARGE 5000 CFS

SCALE IN FEET
50 0 50 100 150

NOTE: ALL VALUES IN PROTOTYPE UNITS.



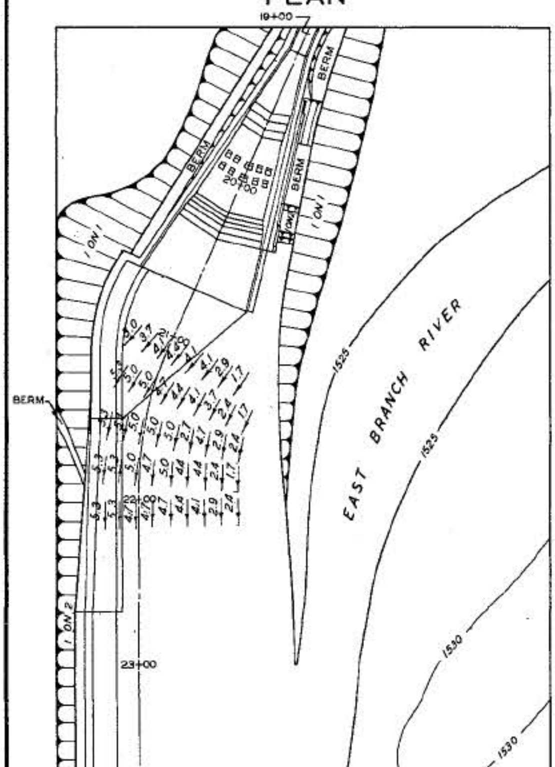
PLAN

MODEL CONDITIONS

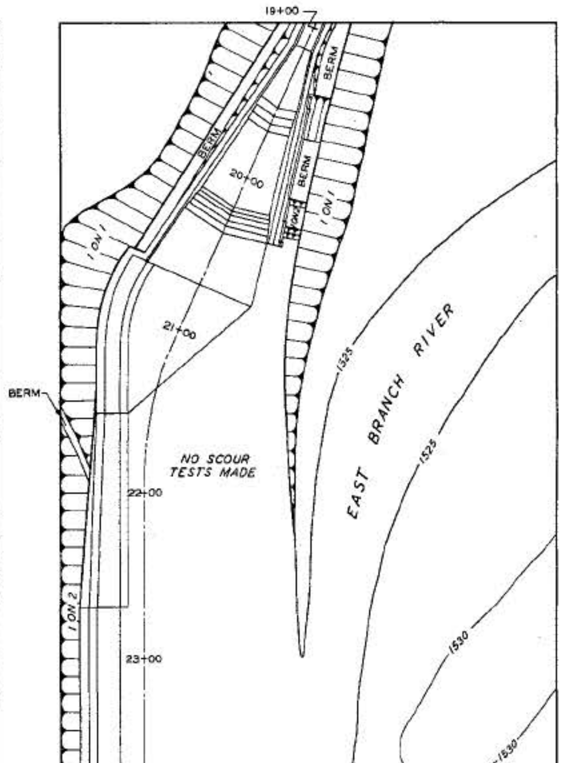
2 ROWS OF BAFFLES
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 0 FT

FLOW CONDITIONS

DISCHARGE	2500 CFS
TAILWATER ELEVATION	1528.5 FT



BOTTOM VELOCITIES



SCOUR PATTERN

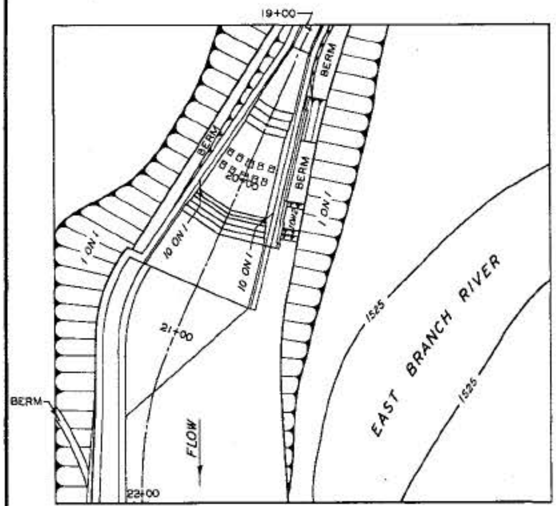
VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

TWO ROWS BAFFLES
DISCHARGE 2500 CFS

NOTE: ALL VALUES IN PROTOTYPE UNITS.

SCALE IN FEET
50 0 50 100 150



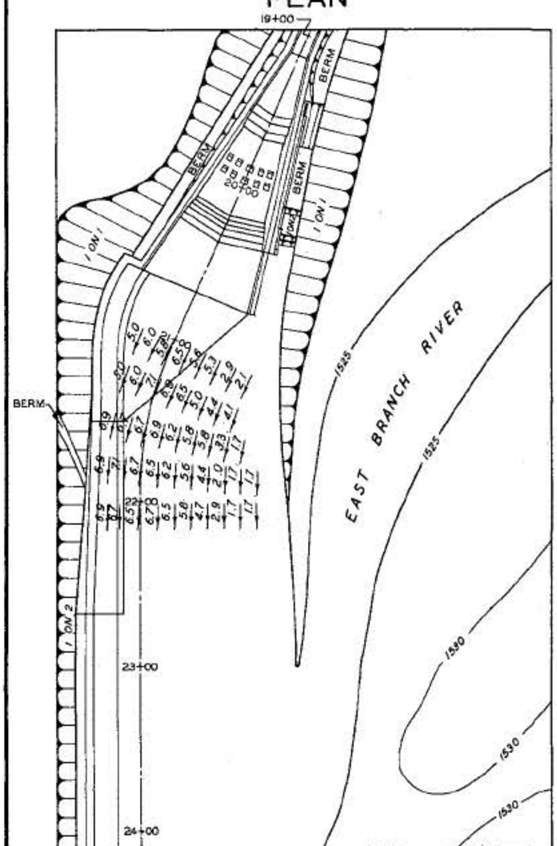
PLAN

MODEL CONDITIONS

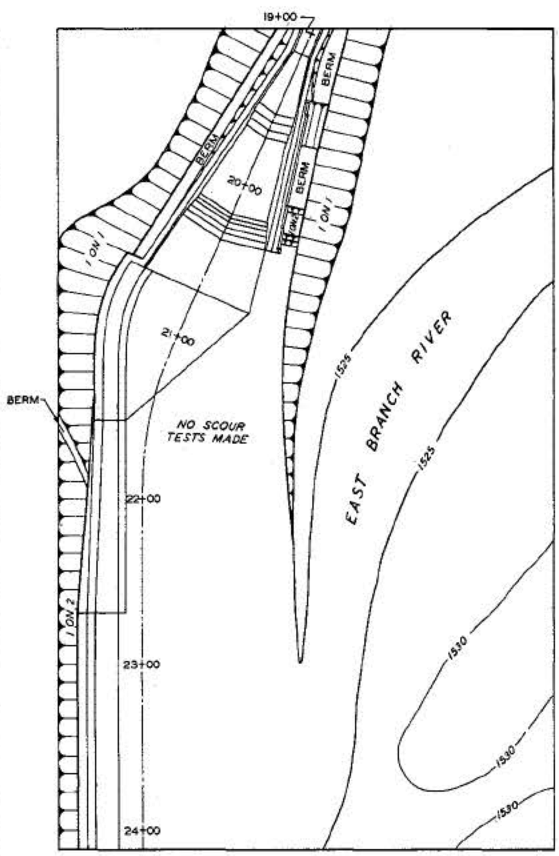
2 ROWS OF BAFFLES
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 0 FT

FLOW CONDITIONS

DISCHARGE	2500 CFS
TAILWATER ELEVATION	1529.5 FT



BOTTOM VELOCITIES



SCOUR PATTERN

VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

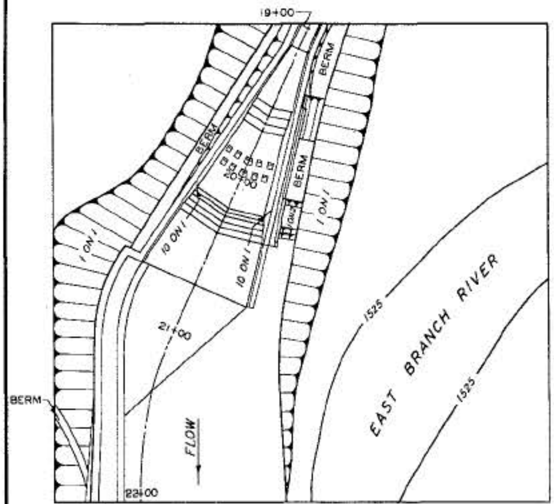
TWO ROWS BAFFLES

DISCHARGE 3500 CFS

SCALE IN FEET

50 0 50 100 150

NOTE: ALL VALUES IN PROTOTYPE UNITS.



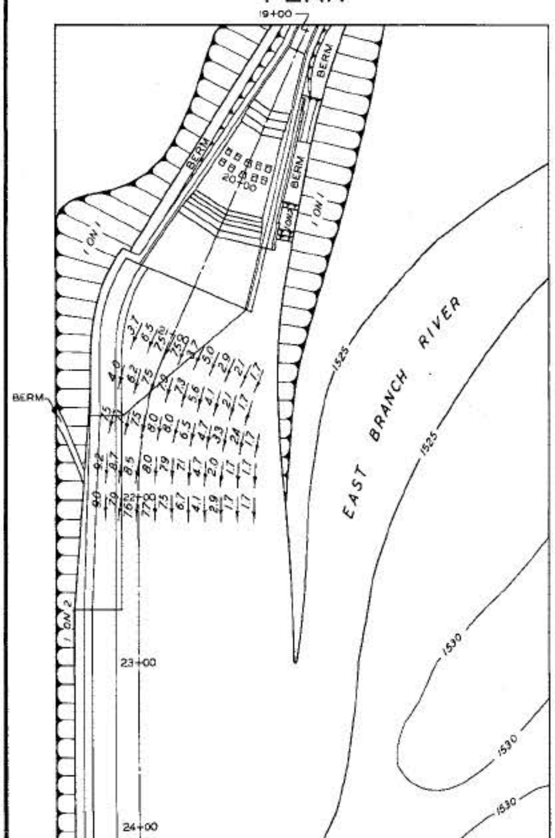
PLAN

MODEL CONDITIONS

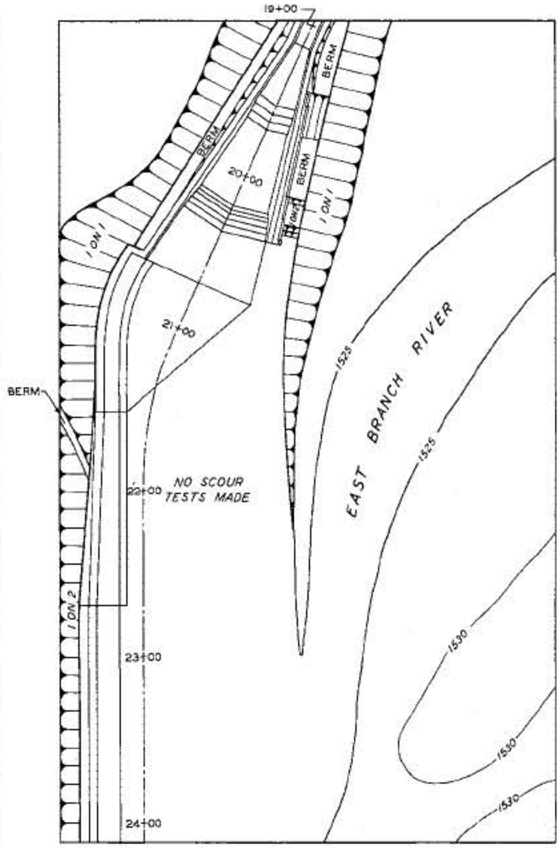
2 ROWS OF BAFFLES
RIGHT TRAINING WALL STRAIGHT
LEFT TRAINING WALL CUT 0 FT

FLOW CONDITIONS

DISCHARGE	5000 CFS
TAILWATER ELEVATION	1531.0 FT



BOTTOM VELOCITIES



SCOUR PATTERN

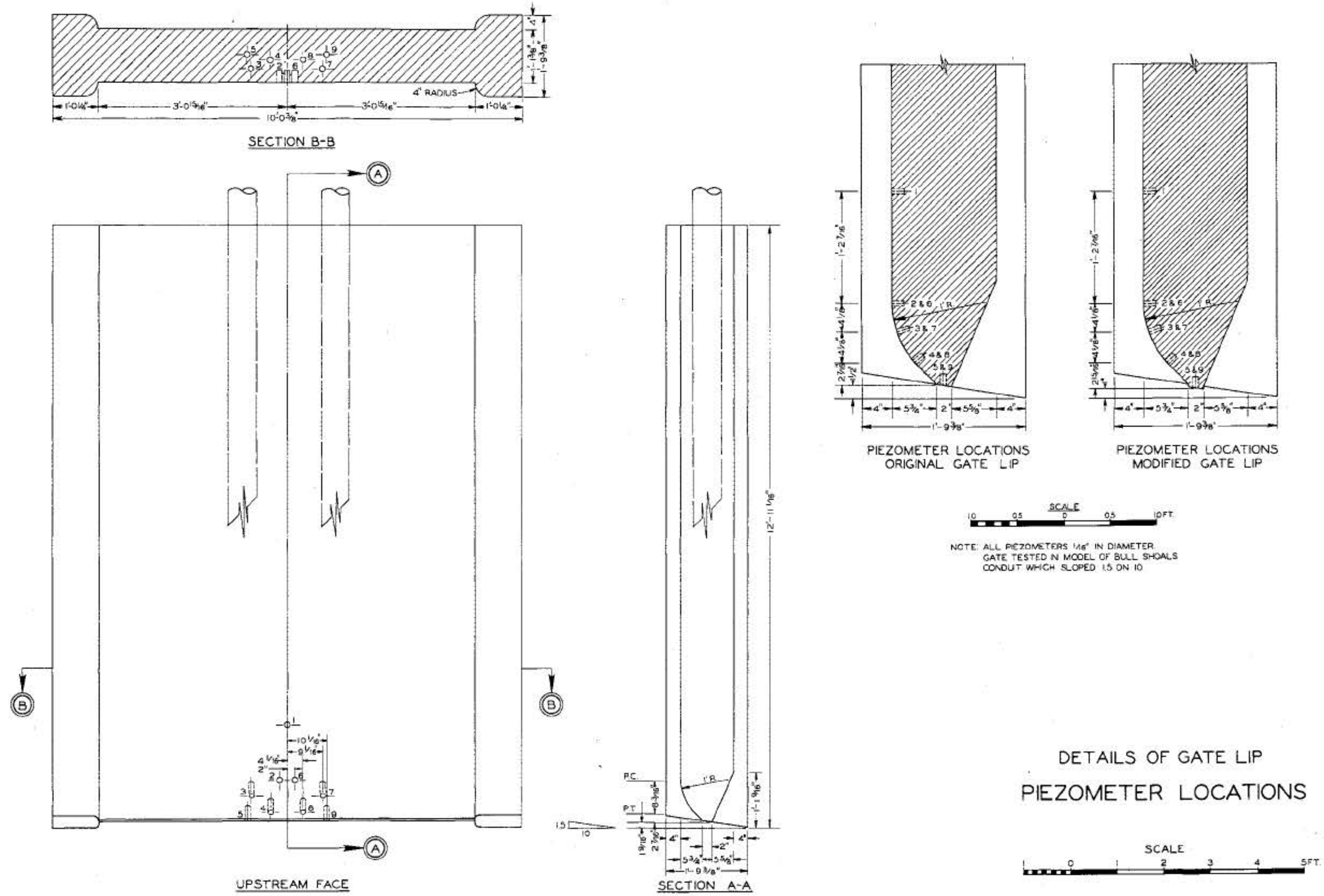
VELOCITIES AND SCOUR

STILLING BASIN AND OUTLET CHANNEL

TWO ROWS BAFFLES
DISCHARGE 5000 CFS

NOTE: ALL VALUES IN PROTOTYPE UNITS.

SCALE IN FEET
50 0 50 100 150

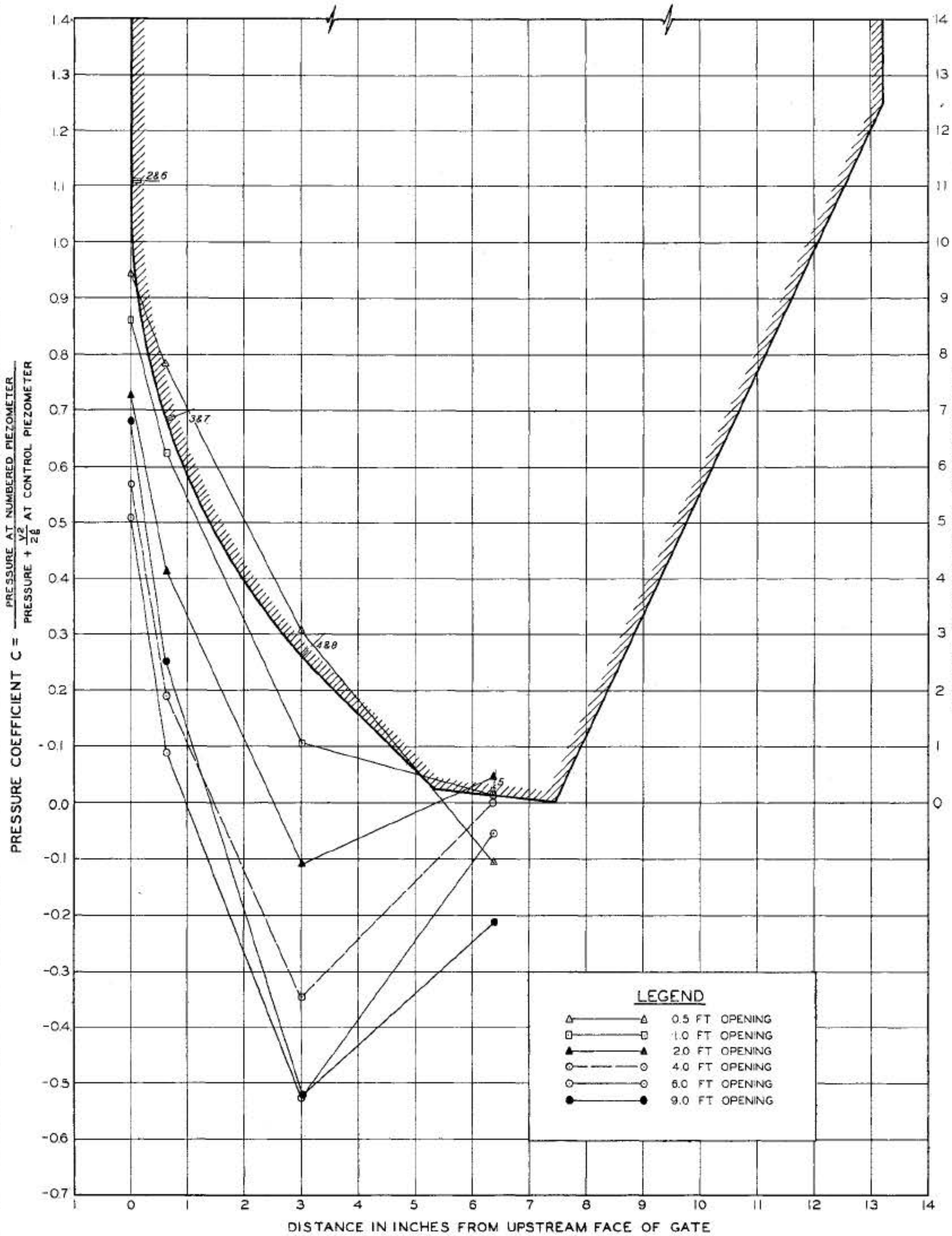


DETAILS OF GATE LIP

PIEZOMETER LOCATIONS

SCALE

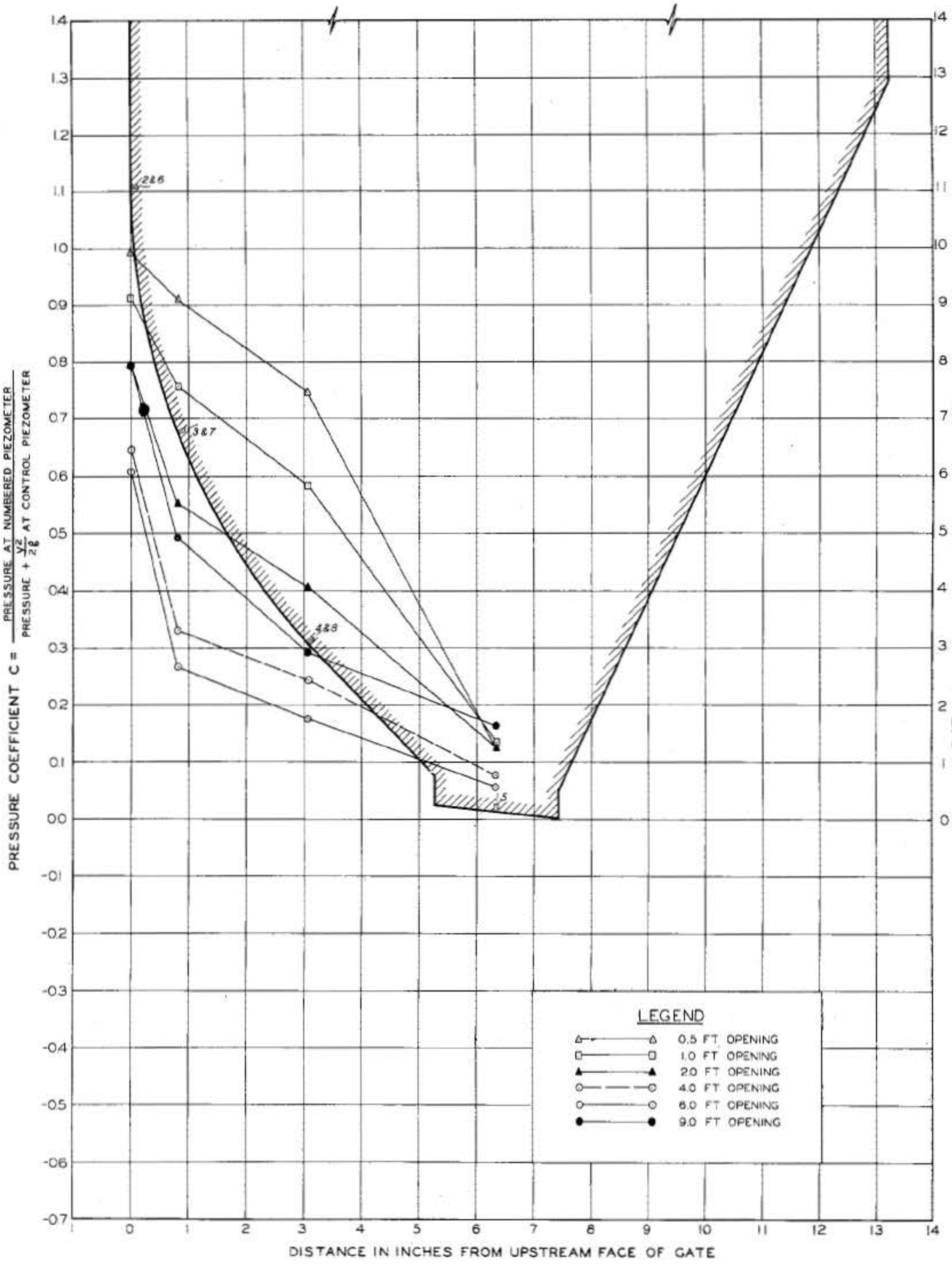
0 1 2 3 4 5 FT.



NOTE: GATE LIP PROFILE AND LOCATION OF PIEZOMETERS SHOWN FOR REFERENCE PURPOSES. FOR EXACT LOCATIONS OF PIEZOMETERS SEE PLATE 49 PIEZOMETER READINGS SHOWN IN TABLES 7-8

PRESSURE COEFFICIENTS

ORIGINAL GATE LIP



NOTE: GATE LIP PROFILE AND LOCATION OF PIEZOMETERS SHOWN FOR REFERENCE PURPOSES. FOR EXACT LOCATIONS OF PIEZOMETERS SEE PLATE 49 PIEZOMETER READINGS SHOWN IN TABLES 9-10

PRESSURE COEFFICIENTS

MODIFIED GATE LIP